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OPERATION CROSSROADS

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REPORT OF

RESTRICTED DATA
ATOMIC ENERGY ACT 1946

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SECTION XIII

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Measurement of

Peak Pressure and Vacuum

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(6) OPERATION CROSSROADS,

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MEASUREMENT OF PEAK PRESSURE AND VACUUM (8)

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Director
Defense Atomic Support Agency
Washington, D. C. 20301

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(10) K. C. Ripley.

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CONFIDENTIAL RESTRICTED DATA
ATOMIC ENERGY ACT 1954

Report On

MEASUREMENT OF PEAK PRESSURE AND VACUUM

This report was prepared by Mr. K. C. RIPLEY, of the Bureau of Ships, who also had charge of these gauges in the field. This work was carried out under the supervision of Comdr. R. M. LANGER, USNR, of the Bureau of Ships.

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ABSTRACT

This report describes the Peak Pressure (Pyrex) gauges that were especially developed for Crossroads tests and presents the test results, conclusions, and recommendations which have resulted from use of these gauges in the Able and Baker Tests.

The conclusions of this report provide information on the following matters of primary interest:

(1) The peak compartment pressure as a function of range in Test Able for each of five main classes of compartment, in three main types of ship. The classes of compartment are: wardroom and cabin spaces; berthing spaces; engine rooms; fire rooms; combined engine and fire rooms. The classes of ship are: destroyers; troop transports; capital ships.

(2) The external peak pressure and external peak vacuum as a function of range in Test Able at ground level, and the corresponding quantities for Test Baker.

(3) The quantities which can be computed when the peak hydrostatic pressure is known, and which when computed completely describe the shock front. These derivable quantities of the shock front are: density; velocity of propagation; mass velocity; and temperature rise. From these derived quantities, the stagnation pressure of the shock front and the head-on reflected pressure of the shock front can be computed.

(4) Information on how other peak pressure determinations compare with corresponding values from the Pyrex gauges, for both Test Able and Test Baker.

(5) The TNT equivalent of the Test Able burst for the actual height of burst, and the TNT equivalent of the Test Baker burst for an imagined surface burst.

(6) Information on the peak pressure from an air burst as a function of height of burst, as computed from the TNT equivalent for the actual height of burst of Test Able.

The present report indicates that the peak pressure-distance graph for Test Able is known to an accuracy of within one or two per cent of the true peak hydrostatic pressure, throughout the range of

about 400 yards to 20,000 yards horizontal distance from center of burst. It is believed that approximately the same statement is true for Test Baker, although some discrepancies appear at ranges under 1000 yards in Test Baker. Due to the large number of measurements of compartment peak pressure in Test Able, the average compartment peak pressure as a per cent of the local external peak pressure is known for any given type of compartment in any given type of ship to an accuracy of within two or three points, that is, within two or three per cent of the local external peak pressure. The measurements of peak vacuum in Tests Able and Baker are considered to be satisfactory, and are believed to be accurate to within two or three per cent of the true peak hydrostatic vacuum, throughout the range of about 1000 yards to 20,000 yards horizontal distance from center of burst.

PART I - INSTALLATION AND DATA

DESCRIPTION OF GAUGES

The gauges reported on herein were developed for the purpose of measuring the peak values of the pressure and vacuum of the blast wave of the atomic bomb on the target vessels, including the interior of the vessels.

The gauges are shown in Figures 1 and 2. The gauges were made from Pyrex tubing, and were carefully annealed and tested for air tightness. It will be noticed that one type of gage is for measuring maximum pressure from blast, and that the other gauge is for measuring maximum vacuum from blast. The gauges as designed are for mounting with the manometer tube upright, and thus are intended for measurement of static pressure only. This means that the gauges do not measure pressure due to wind velocity, except in so far as velocity head of blast may be converted by ship structure into static head of blast.

The operation of the gauges is as follows: A pressure pulse (or vacuum pulse) will compress (or rarify) air in the open manometer tube. This pressure (or vacuum) will bubble air through the liquid of the pressure gauge only (or vacuum gauge only), until equilibrium is established between absolute pressure of entrapped air and absolute pressure of outside air. When the pressure pulse (or vacuum pulse) has passed, the entrapped air has been left free to expand (or to contract), and this expansion (or contraction) when completed has caused liquid to rise and to stand in the open (or closed) manometer tube. The height of rise of liquid in the manometer tube is a direct measurement of the peak intensity of the pressure (or vacuum) pulse. It is noteworthy that only the pressure gauge will register a pressure pulse, and that only the vacuum gauge will register a vacuum pulse.

The height of rise of the liquid can be converted into peak pressure of blast by use of Figures 3 or 4, as appropriate. The calibration curves there shown have been derived by exact calculation, on basis of two assumptions only. The first assumption is that the changes in volume of entrapped air during passage of a pulse are adiabatic. The second assumption is that the changes of temperature of the gauge from time of filling of the gauge to time of reading of the gauge either are moderate in amount, or are sufficiently well known to allow a correc-

tion to be made for temperature susceptibility of the gauge. Inspection of Figures 3 and 4 will show that all gauge readings are measured from the bottom of the manometer tube, and that these measurements allow for an initial small setting of liquid left standing in the manometer tube. Inspection of Figure 3 further will show that the sensitivity of reading of the pressure gauge can be varied at will, as determined by the amount of liquid used for filling the gauge.

The calibration curves of Figures 3 and 4 are for use when the duration of the peak pressure (or vacuum) is known to be long as compared with the time of response of the gauge. The exact time of response of the gauges for any given pressure to be measured is not known, but from exploratory tests conducted by the David Taylor Model Basin, it appears that the response time of the pressure gauge is not greater than 10 or 20 milliseconds. The blast wave from an atomic bomb is said to have a period of roughly one second, which is 100 times 10 milliseconds. Thus for measurement of maxiumum blast from an atomic bomb, the present gauges were expected to prove to be entirely adequate.

The liquid used for filling the gauges was colored water, green for Test Able gauges and red for Test Baker gauges. Two fillings for Test Able pressure gauges were used, namely, one of 126 c.c. ("H" equal to 0.0) for all ships beyond 1000 yards from center of the target array, and one of 144 c.c. ("H" equal to 0.5) for all ships within 1000 yards from center of the target array. The initial setting used for virtually all of the Test Able pressure gauges was 1.5 c.c. of water plus 2.5 c.c. of vacuum pump oil. The purpose of the oil was to prevent evaporation of the water, and to facilitate reading of the gauge following test. The filling used for all Test Able vacuum gauges was 144 c.c. of water followed by 4 c.c. of vacuum pump oil. No liquid was added for an initial setting of the vacuum gauges, that is, the initial level of liquid in the closed manometer tube was made to be at bottom of the tube.

Pressure gauges recovered from Test Able showed that the oil used for setting the gauges was not all pushed through even when the reading from a gauge was considerable. This observation lead to the conclusion that the viscosity of the oil caused air to rush down through a small opening forced in the oil, and that accordingly it was incorrect to measure the column of liquid as being to the top of the oil in the manometer tube. The procedure adopted was to measure to bottom of the oil topping, for all pressure gauge readings. Readings of 5/16 inch of water (equivalent to 0.2 pound per square inch) were considered to be real only if some of the oil was seen to have been pushed through into bulb of the gauge. Thus it was a matter of ease to obtain pressure

readings to the nearest 0.1 pound per square inch (equivalent to measuring to the nearest 5/32 inch) all of the way down to 0.2 pound per square inch. No distinction could be made between a pressure of 0.0 and one of 0.1 pound per square inch, and therefore all readings within this range were arbitrarily called zero readings. Vacuum gauges recovered from Test Able frequently showed a sizeable topping of oil within the closed manometer tube. Since this oil could only have come from oil originally in bulb of the gauge, it was considered to be the correct procedure to measure to <u>top</u> of such oil, in this case.

[redacted]

INSTALLATION AND DATA, TEST ABLE

Two hundred fifty gauges were installed in Test Able. The detailed location of these gauges, and the data from them are listed on the data sheets, pages 7 to 32 inclusive. For ready reference, the gauges are summarized by vessels as follows:

VESSEL	No. of Pressure Gauges	No. of Vacuum Gauges
GILLIAM, BRISCOE, CATRON, BRACKEN, BLADEN, NIAGARA, each	7	2
BRULE	8	4
BANNER	7	3
RALPH TALBOT, LAMSON, RHIND MUSTIN, MUGFORD, WAINWRIGHT, each	6	2
HUGHES	7	3
PENSACOLA	8	3
SALT LAKE CITY	8	2
NEVADA		3
ARKANSAS	11	2
PENNSYLVANIA	13	2
NEW YORK	8	2
SARATOGA	13	2
INDEPENDENCE	10	1
SKATE	2	0
PRINZ EUGEN	8	2
NAGATO	6	1

Of these 250 gauges, 196 were pressure gauges, 54 were vacuum gauges. Seventeen gauges were on ships which were sunk, and twenty gauges were broken; 213 gauges were recovered. Of these, 190 are considered to give significant readings - 183 compartment gauges, seven external gauges; seven gauges were upset, and the readings of 16 were regarded as indeterminate.

The assessment of "indeterminate" was for various causes: oil having disappeared from the gauge, the gauge having overflowed or having been flooded, or a reading obviously out of line with other gauges.

The latter cause applies particularly to a vacuum gauge - e.g., BLADEN, gauge 5 - 3(page 11) - and may possible have an explanation in the temperature susceptibility of the vacuum gauge. This tempera-

ture susceptibility arises from the use of water instead of low volatile liquid for filling the gauge. The effect of using water in the vacuum gauge is that as the temperature of the gauge is caused to rise from the gauge having been installed in a hot fire room or hot engine room, the increasing vapor pressure in the closed manometer tube forces air out of the tube. When the gauge is allowed to cool down without any vacuum pulse having passed, the erroneous reading of vacuum will be as shown by Figure 5. If, however, a vacuum pulse greater than the erroneous reading passed after the gauge had cooled, the gauge would read correctly, providing that all of the water standing in the manometer tube was drawn down into bulb of the gauge. (If due to viscosity of the water, some of the water was left clinging to the manometer tube, the gauge would read proportionately high.) If, on the other hand, the vacuum pulse passed while the gauge was still at maximum temperature, the vacuum pulse would add to the erroneous reading which would appear after the gauge had cooled down. Thus to correct for temperature susceptibility, one should know both the temperature of the gauge at time of passage of the vacuum pulse, and the maximum temperature obtained prior to the pulse.

It is believed that the use of di-butyl-phthalate would have alleviated this situation in the vacuum gauges, and this substance was ordered. However, it was not received for use in the installation. Although that liquid is too sluggish for safe use in the pressure gauges, it is felt that the slow decay of the positive phase of the shock wave would enable the liquid to fall back in the vacuum gauges and leave the vacuum readings undistorted.

The mounting of the gauges was divided between a swinging suspension, and a shock mounting which held the gauges from swinging bodily. All external gauges had the latter mounting.

INSTALLATIONS AND DATA, TEST BAKER

It was felt that the data of Test Able provided good coverage on the study of internal peak pressure as a function of external peak pressure, and the installations in Test Baker were principally external. Eighty-one gauges were installed on 20 vessels. The detailed locations and the readings obtained are listed on the data sheets, pages 33 to 52 inclusive. The installations by vessels are as follows (not including gauges placed in the condensers of certain vessels):

VESSEL	No. of Pressure Gauges	No. of Vacuum Gauges
BANNER, BLADEN, BRACKEN BRISCOE; NIAGARA, each	2	1
MAYRANT, MUSTIN, RHIND, WAINWRIGHT, WILSON, each	2	1
ARKANSAS, NEVADA, NEW YORK, PENNSYLVANIA, PRINZ EUGEN, SARATOGA, INDEPENDENCE, SALT LAKE CITY, each	4	1
PENSACOLA	3	1
NAGATO	6	1

Fifty-eight gauges were recovered; 17 were lost on vessels sunk in the test, and six were broken. Of the 58, 48 readings were significant; five were upset and five were indeterminate.

It was expected that the peak pressures in Test Baker might be between one-half and one-tenth of those recorded at corresponding locations in Test Able. Accordingly, more sensitive fillings were used in the pressure gauges - viz., 108 c.c. of liquid ("H" equal to minus 1/2 inch) for destroyers and transports, 117 c.c. of liquid ("H" equal to minus 1/4 inch) for the capital ships. The slightly less sensitive filling was used on the capital ships since these were generally closer to the explosion. The setting of all pressure gauges (setting is defined as the liquid above the bottom of the manometer tube, within the tube, at completion of filling) was 1 c.c. of water plus 2.5 c.c. of vacuum pump oil. The filling and setting of the vacuum gauges was as for Test Able.

DATA SHEET, TEST ABLE
(1) APA-57, GILLIAM

STATION	TYPE OF GAGE	COMPARTMENT	REMARKS
1-1	(P)	Wardroom, B-0108L	Ship sunk in Test Able
-2	(V)	Wardroom, B-0108L	
-3	P	Wardroom, B-0108L	
-4	(P)	Engine Room, B-3-1E	
-5	P	Engine Room, B-3-1E	
-6	(P)	External, Flying Bridge	
-7	P	Troop Berthing, C-101L	
-8	V	Troop Berthing, C-101L	
-9	P	Troop Berthing, C-102L	

DATA SHEET, TEST ABLE
(2) APA-65, BRISCOE

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
2-1	(P)	External, Flying Bridge	Upset		-
-2	(V)	External, Flying Bridge	Broken		-
-3	(P)	Wardroom, B-0108L	1/4	3/4	0.0
-4	P	Wardroom, B-0108L	No reading		0.0
-5	(P)	Engine Room, B-1-1E	5/16	3/4	0.2
-6	P	Engine Room, B-1-1E	1 9/16	1/8	1.0
-7	P	Berthing, C-202-L	No reading		0.0
-8	P	Berthing, C-201-L	No reading		0.0
----9	V	Berthing, C-201-L	3/4	0	-0.3

DATA SHEET, TEST ABLE
(3) APA-71, CATRON

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
3-1	(V)	Wardroom, B-0108-L	1 3/4	1/8	-1.2
-2	(P)	Wardroom, B-0108-L	5/16	5/8	0.0
-3	P	Wardroom, B-0108-L	7/16	1/16	0.2
-4	P	Engine Room, B-1-1E	1/4	1/2	0.2
-5	V	Engine Room, B-1-1E	4 1/16	1/16	-
-6	(P)	Berthing, C-201-L	1/4	9/16	0.0
-7	(P)	Berthing, C-201-L	No reading		0.0
-8	P	Berthing, C-101-L	No reading		0.0
-9	P	Engine Room, B-3-1E	1/2	9/16	0.3

DATA SHEET, TEST ABLE
(4) APA-64, BRACKEN

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
4-1	(P)	External, Flying Bridge	4 5/8	3/8	2.9
-2	(V)	External, Flying Bridge	2 1/2	1/8	-1.6
-3	(P)	Wardroom, B-0108-L	3/8	7/16	0.2
-4	V	Wardroom, B-0108-L	1 3/8	3/16	-1.0
-5	P	Engine Room, B-3-1E	3/8	3/4	0.0
-6	P	Engine Room, B-3-1E	5/8	0	-
-7	P	Berthing, C-201-L	13/16	9/16	0.5
-8	P	Berthing, C-201-L	3/8	5/8	0.2
-9	P	Berthing, C-102-L	2 3/4	11/16	1.7

DATA SHEET, TEST ABLE
(5) APA-63, BLADEN

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
5-1	(P)	Wardroom, B-0108-L	3/8	1/2	0.0
-2	(V)	Wardroom, B-0108-L	1 1/16	0	-0.6
-3	V	Engine Room, B-3-1E	4 3/4	1/16	-
-4	P	Engine Room, B-3-1E	1/2	3/4	0.4
-5	P	Cargo Hold No. 2	No reading		0.0
-6	P	Cargo Hold No. 2	No reading		0.0
-7	(P)	Berthing, C-201-L	5/8	1/2	0.4
-8	P	Berthing, C-201-L	1/4	3/16	0.2
-9	P	Berthing, C-202-L	No reading		0.0

DATA SHEET, TEST ABLE
(6) APA-87, NIAGARA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
6-1	(P)	Wardroom, B-0108-L	5/16	7/16	0.0
-2	(P)	External, Flying Bridge	2 15/16	3/8	1.8
-3	(V)	External, Flying Bridge	1 3/8	1/8	-0.9
-4	P	Engine Room, B-3-1E	No reading		0.0
-5	V	Engine Room, B-3-1E	No reading		0.0
-6	P	Cargo Hold, No. 2	No reading		0.0
-7	P	Cargo Hold No. 2	No reading		0.0
-8	P	Berthing, C-201-L	No reading		0.0
-9	P	Berthing, C-202-L	No reading		0.0

DATA SHEET, TEST ABLE
(7) APA-66, BRULE

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
7-7	(P)	Wardroom, B-0108-L	9 15/16	5/16	8.3
-2	P	Wardroom, B-0108-L	Broken		-
-11	(V)	Wardroom, B-0108-L	Broken		-
-10	V	Wardroom, B-0108-L	Broken		-
-6	(P)	Berthing, C-102-L	4 15/16	3/16	4.0
-1	P	Berthing, C-102-L	Broken		-
-12	(V)	Berthing, C-102-L	2 13/16	1/4	-1.9
-9	V	Berthing, C-102-L	3 1/8	1/4	-2.1
-5	(P)	Engine Room, B-3-1E	2 1/8	3/8	1.7
-3	P	Engine Room, B-3-1E	5 1/16	1/8	4.1
-8	(P)	Berthing, C-101-L	3 11/16	3/16	2.9
-4	P	Berthing, C-101-L	4 15/16	3/16	4.0

DATA SHEET, TEST ABLE
(8) CA-24, PENSACOLA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
8-5	(P)	Berthing, D-203-L	Broken		-
-12	(V)	Berthing, D-203-L	Broken		-
-2	P	Berthing, D-203-L	Overflow		-
-7	(P)	Wardroom	1/2	5/16	0.5
-11	(V)	Wardroom	1 5/8	1/16	-1.0
-1	P	Executive Officer's Cabin	4 5/8	1/4	3.7
-8	(P)	Engine Room, Forward	4 3/16	1/2	3.3
-3	P	Engine Room, Forward	3 5/8	3/8	2.9
-9	V	Engine Room, Forward	4 5/8	5/16	-3.0
-6	(P)	Fire Room, B-1	4 1/8	3/8	3.3
-4	P	Crossroads Office	Broken		-

DATA SHEET, TEST ABLE
(9) DD-410, HUGHES

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
9-1	(P)	Berthing, C-203-LM	1/2	1/8	0.5
-2	(V)	Berthing, C-203-LM	2 5/16	1/8	-1.6
-3	P	Berthing, C-203-LM	15/16	3/16	0.7
-4	V	Berthing, C-203-LM	2 11/16	1/8	-1.8
-5	(P)	Cabin, 107	7/16	5/16	0.4
-6	(V)	Cabin, 107	1 13/16	1/8	-1.2
-7	(P)	Fire Room, B-1-1	2 9/16	5/16	2.0
-8	(P)	Engine Room, B-3-1	2 3/16	5/16	1.7
-9	P	Armory, A-404-M	No reading		0.0
-10	P	Armory, A-404-M	No reading		0.0

DATA SHEET, TEST ABLE (10) APA-60, BANNER

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
10-1	(P)	Wardroom, B-0108-L	1/4	9/16	0.0
-2	(V)	Wardroom, B-0108-L	1 13/16	1/16	-1.2
-3	P	Wardroom, B-0108-L	7/16	7/16	0.3
-4	(P)	Berthing, C-101-L	5/16	1/2	0.2
-5	(V)	Berthing, C-101-L	3/4	0	-0.5
-6	P	Berthing, C-102-L	11/16	1/2	0.6
-7	V	Berthing, C-102-L	1 3/8	3/16	-1.0
-8	P	Berthing, C-201-L	5/8	3/8	0.5
-9	(P)	Engine Room, B-3-1E	2 1/16	1/4	1.6
-10	P	Engine Room, B-3-1E	Broken		-

DATA SHEET, TEST ABLE (11) DD-390, RALPH TALBOT

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
11-1	P	Berthing, D-208-AL	1 1/16	1/8	0.8
-2	(V)	Berthing, D-208-AL	1 1/2	0	-0.9
-3	(P)	Cabin, 101	3/8	1/4	0.3
-4	(P)	Engine Room, B-4-1	5/16	11/16	0.0
-5	P	Engine Room, B-4-1	No reading		0.0
-6	V	Engine Room, B-4-1	No reading		0.0
-7	P	Fire Room, B-1-1	3 3/8	1/2	2.7
-8	P	Fire Room, B-1-1	2 7/8	7/16	2.3

DATA SHEET, TEST ABLE
(12) DD-367, LAMSON

STATION	TYPE OF GAGE	COMPARTMENT	REMARKS
12-1	(V)	Berthing, D-209-L	Ship sunk in Test Able.
-2	(P)	Berthing, D-209-L	
-3	P	Engine Room, B-4-1	
-4	V	Engine Room, B-4-1	
-5	(P)	Engine Room, B-4-1	
-6	P	Fire Room, B-1-1	
-7	P	Fire Room, B-1-1	
-8	P	Cabin, 105	

DATA SHEET, TEST ABLE
(13) DD-404, RHIND

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
13-1	P	Berthing, C-204-L	5/8	5/8	0.4
-2	P	Berthing, C-204-L	5/8	5/8	0.4
-3	P	Fire Room, B-2-1	1 7/8	3/8	1.2
-4	V	Fire Room, B-2-1	3 3/8	7/16	-2.3
-5	P	Engine Room, B-4-1	7/8	3/8	0.5
-6	(V)	External	Broken		-
-7	(P)	External	Broken		-
-8	(P)	Cabin, 101	3/8	3/4	0.0

DATA SHEET, TEST ABLE
(14) DD-413, MUSTIN

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
14-1	(P)	Gun Mount No. 2	1 13/16	3/16	1.1
-2	(V)	Gun Mount No. 2	Broken		-
-3	(P)	Berthing, C-203-LM	1	3/16	0.6
-4	P	Engine Room, B-4-1	Upset		-
-5	V	Engine Room, B-4-1	3 1/4	1/8	-
-6	P	Fire Room, B-1-1	No reading		0.0
-7	P	Handling Room, A-104-1MT	No reading		0.0
-8	P	Cabin, 102	5/16	11/16	0.0

DATA SHEET, TEST ABLE
(15) DD-389, MUGFORD

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
15-1	(V)	External, Superstructure	15/16	0	-0.5
-2	(P)	External, Superstructure	3 1/4	1/4	2.0
-3	P	Engine Room, C-1	0	7/16	0.0
-4	V	Engine Room, C-1	2 10/16	1/16	-
-5	P	Fire Room, B-1-1	11/16	5/16	0.4
-6	P	Fire Room, B-1-1	13/16	5/8	0.5
-7	P	Berthing, D-210-L	2 3/8	5/8	1.4
-8	(P)	Captain's Cabin	9/16	3/16	0.0

TOP SECRET

DATA SHEET, TEST ABLE

(16) DD-419, WAINWRIGHT

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	READING (inches) OIL	PRESSURE Lbs/sq.in.
16-1	P	Engine Room, B-3-1	11/16	11/16	0.6
-2	V	Engine Room, B-3-1	4 1/8	1/8	-
-3	P	Fire Room, B-1-1	1 5/8	3/8	1.0
-4	(P)	Gun Mount No. 2	3 3/4	3/16	2.4
-5	(V)	Gun Mount No. 2	2 9/16	1/16	-1.6
-6	(P)	Berthing, C-204-L	1 11/16	7/16	1.0
-7	P	Handling Room, A-103L	1 1/8	5/8	0.7
-8	P	Cabin, 103	1/4	11/16	0.0

DATA SHEET, TEST ABLE
(17) BB-36, NEVADA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
17-1	(P)	Wardroom, A-126-L	5/16	3/8	0.3
-2	(V)	Wardroom, A-126-L	Broken		-
-3	P	Wardroom, A-126-L	1 1/8	5/8	0.9
-4	(P)	Berthing, C-291-1L	8	3/16	6.6
-5	P	Berthing, C-291-1L	Upset		-
-6	V	Berthing, C-291-1L	11	3/8	-6.4
-7	P	Engine Room, C-4-E	3/4	3/4	0.6
-8	(P)	Engine Room, C-4-E	1 13/16	9/16	1.4
-9	P	Fire Room, B-6-E	7/8	0	-
-10	P	Fire Room, B-6-E	2 7/8	1/2	2.3
-11	P	Turret No. 2, Handling Room	15/16	5/16	0.8
-12	V	Turret No. 2, Handling Room	3 3/8	0	-2.1

DATA SHEET, TEST ABLE
(18) IX-300, PRINZ EUGEN

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
18-1	(P)	Turret B, Gun Chamber	8 11/16	5/8	5.7
-2	P	Turret B, Handling Room	No reading		0.0
-3	(P)	Berthing, B-201-1L	2 9/16	1/4	1.6
-4	P	Berthing, A-307-L	3 3/8	3/4	2.1
-5	P	Engine Room, Aft.	2 1/4	11/16	1.4
-6	V	Engine Room, Aft.	4	3/16	-2.5
-7	P	Fire Room, 1, 6.	2 3/4	7/16	1.7
-8	P	Fire Room, 1, 6.	2	1/2	1.2
-9	P	Cabin 277	1/2	7/16	0.3
-10	V	Cabin 277	7/8	1/4	-0.7

DATA SHEET, TEST ABLE
(19) BB-33, ARKANSAS

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
19-1	P	Turret No. 2, Handling Room	1 7/16	5/8	1.1
-2	V	Turret No. 2, Handling Room	3 1/8	5/16	-2.1
-3	P	Berthing, C-105	1/8	11/16	0.0
-4	(V)	Berthing, C-105	1 3/4	0	-1.0
-5	P	Berthing, C-105	3/8	5/8	0.0
-6	P	Engine Room, C-2	1/8	13/16	0.0
-7	(P)	Engine Room, C-2	5/16	0	-
-8	P	Mess, A-122-S	0	11/16	0.0
-9	(P)	Mess, A-122-S	0	7/16	0.0
-10	P	Engine Room, C-3	0	3/4	0.0
-11	(P)	Fire Room, B-1	5 1/4	1/2	4.2
-12	(P)	Turret No. 6, Handling Room	2 3/4	1/2	2.2
-13	(P)	Turret No. 3, Gun Chamber	13/16	7/16	0.6

DATA SHEET, TEST ABLE
(20) CV-3, SARATOGA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
20-1	P	Passageway, B-0208-T	-	-	0.0
-2	V	Passageway, B-0208-T	-	-	0.0
-3	P	Wardroom, A-0115-L	-	-	0.0
-4	(P)	Wardroom, A-0115-L	-	-	0.0
-5	P	Berthing, A-118-L	-	-	0.4
-6	(P)	Elevator Pit	0	5/16	-
-7	(V)	Elevator Pit	1 1/16	0	-0.6
-8	P	Central Station, A-449-C	13/16	1/4	0.5
-9	P	Trunk Space, C-332	1/8	0	-
-10	P	Passage, C-333-E	-	-	0.0
-11	(P)	Gun Mount No. 5	Upset		-
-12	(P)	Director, Mark 37	Upset		-
-13	P	Gun Mount No. 6, Handling Room	1/2	3/8	0.3
-14	P	Gun Mount No. 6, Handling Room	11/16	1/2	0.4
-15	P	Gun Mount No. 7, Handling Room	5/16	7/16	0.3

DATA SHEET, TEST ABLE
(21) BB-38, PENNSYLVANIA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	READING (inches) OIL	PRESSURE lbs/sq.in.
21-1	V	Wardroom, D-602	1	0	-0.6
-2	P	Wardroom, D-602	No reading		0.0
-3	P	Passageway, D-504	No reading		0.0
-4	P	Berthing, A-704	3/16	1/16	-
-5	(V)	External, Emergency	Broken		-
-6	(P)	External, Lookout	Upset		-
-7	P	Engine Room, C-202	No reading		0.0
-8	(P)	Engine Room, C-202	0	3/4	0.0
-9	P	Fire Room, B-202	2	5/16	1.3
-10	(P)	Fire Room, B-202	2 1/4	1/2	1.4
-11	P	Turret No. 3, Magazine	Locked		-
-12	(P)	Turret No. 1, Gun Room	2 11/16	1/16	1.7
-13	P	Gun Mount, Handling Room	Unrecorded		0.0
-14	(P)	Director, Mark 37, Port	Upset		-
-15	P	Director, Mark 34, Aft.	3 11/16	3/8	2.3

DATA SHEET, TEST ABLE
(22) BB-34, NEW YORK

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
22-1	P	Fire Room, B-2	1 9/16	7/16	1.0
-2	P	Fire Room, B-2	1	1/2	0.6
-3	(P)	Berthing, D-111	3/8	3/4	0.0
-4	(P)	Wardroom, A-126	1 1/16	9/16	0.7
-5	P	Wardroom, A-123	3/8	11/16	0.0
-6	(P)	Turret No. 3, Gun Chamber	1 5/16	3/8	0.8
-7	P	Turret No. 3, Handling Room	3/8	11/16	0.0
-8	P	Engine Room, C-1	-	-	0.0
-9	V	Engine Room, C-2	2 7/16	1/4	-1.7
-10	(V)	Engine Room, C-1	Broken		-

DATA SHEET, TEST ABLE
(23) CA-25, SALT LAKE CITY

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
23-1	(V)	Wardroom, A-104-L	Broken		-
-2	(P)	Wardroom, A-104-L	3 3/4	5/8	3.0
-3	V	Berthing, D-305-L	7/8	1/16	-0.5
-4	P	Berthing, D-305-L	15/16	1/4	0.8
-5	(P)	Engine Room, C-1	2 5/8	1/4	2.1
-6	P	Engine Room, C-1	2 3/16	9/16	1.7
-7	P	Fire Room, B-1-E	7 5/16	1/2	6.0
-8	P	Fire Room, B-1-E	3 1/16	1/4	2.4
-9	P	Handling Room, A-427-M	5/16	3/4	0.0
-10	(P)	Berthing, C-201-L	Broken		-

DATA SHEET, TEST ABLE
(24) NAGATO (ex-Jap BB)

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
24-1	P	Engine Room, Center, Control	4 3/16	3/8	3.3
-2	P	Engine Room, Center, Main	2 1/16	3/8	1.6
-3	V	Engine Room, Port	2 15/16	1/16	-1.8
-4	P	Engine Room, Port	5/8	3/8	0.6
-5	P	Fire Room, No. 2	4 13/16	5/16	3.8
-6	P	Fire Room, No. 2	Flooded		-
-7	(P)	Turret No. 1, Gun Chamber	1 13/16	5/8	1.3

DATA SHEET, TEST ABLE
(25) CVL-22, INDEPENDENCE

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
25-1	(P)	Fire Room, B-1	1/4	1/16	-
-2	P	Fire Room, B-1	1	1/2	0.8
-3	P	Engine Room, B-2	3/16	9/16	0.0
-4	P	Engine Room, B-2	3/16	3/16	-
-5	P	Engine Room, B-4	15/16	9/16	0.7
-6	(P)	Engine Room, B-4	15/16	9/16	0.7
-7	P	Berthing, C-202-L	Broken		-
-8	V	Berthing, C-202-L	1 3/8	3/8	-1.1
-9	(P)	Cabin, A-210-L	2 5/8	5/8	2.1
-10	P	Berthing, C-308-L	Broken		-
-11	(P)	Hanger Deck	Broken		-

DATA SHEET, TEST ABLE
(26) SS-305, SKATE

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
26-1	(P)	Forward Torpedo Room	1 3/8	3/16	0.9
-2	(P)	Berthing	0	5/8	0.0

DATA SHEET, TEST BAKER
(1) APA-87, NIAGARA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	READING (inches) OIL	PRESSURE lbs/sq.in.
1-1	(V)	External, Sky Lookout	1 3/4	1/16	-1.1
-2	(P)	External, Sky Lookout	2 5/8	1/4	1.2
-3	(P)	External, Bridge, Port	2 1/4	1/4	1.1

DATA SHEET, TEST BAKER
(2) APA-63, BLADEN

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
2-1	(V)	External, Sky Lookout	1 11/16	1/16	-1.1
-2	(P)	External, Sky Lookout	3 1/8	3/16	1.5
-3	(P)	External, Bridge, Port	3 1/16	1/4	1.4

DATA SHEET, TEST BAKER
(3) APA-64, BRACKEN

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	READING (inches) OIL	PRESSURE lbs/sq.in.
3-1	(V)	External, Sky Lookout	2	1/4	-1.4
-2	(P)	External, Sky Lookout	3 3/4	3/8	1.7
-3	(P)	External, Bridge, Port	8 11/16	1/4	-

DATA SHEET, TEST BAKER
(4) APA-65, BRISCOE

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
4-1	(V)	External, Sky Lookout	3 1/16	5/16	-2.1
-2	(P)	External, Sky Lookout	2 1/4	7/16	1.1
-3	(P)	External, Sky Lookout, Port	Broken		-

DATA SHEET, TEST BAKER
(5) APA-60, BANNER

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
5-1	(V)	External, Sky Lookout	2 1/16	1/16	-1.3
-2	(P)	External, Sky Lookout	3 11/16	1/4	1.7
-3	(P)	External, Bridge, Port	3 15/16	1/4	1.8

TOP SECRET

DATA SHEET, TEST BAKER
(6) DD-413, MUSTIN

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
6-1	(V)	Internal, Director	1 3/8	1/16	-0.9
-2	(P)	Internal, Director	5 3/16	9/16	2.4
-3	(P)	External, Gun Deck, Aft	5 1/16	7/16	2.4

DATA SHEET, TEST BAKER
(7) DD-402, MAYRANT

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
7-1	(V)	External, Director	1 3/4	1/2	-1.4
-2	(P)	External, Director	3 7/8	3/16	1.8
-3	(P)	External, Gun Deck Stbd.	6 1/4	1/2	

DATA SHEET, TEST BAKER
(8) DD-408, WILSON

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
8-1	(V)	External, Chart House, Port	Upset		-
-2	(P)	External, Chart House, Port	Upset		-
-3	(P)	External, Gun Deck, Stbd.	3 1/8	5/16	1.4

DATA SHEET, TEST BAKER
(9) DD-404, RHIND

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
9-1	(V)	Internal, Director	1 1/4	1/8	-0.9
-2	(P)	Internal, Director	3 1/4	3/8	1.5
-3	(P)	External, Gun Deck, Stbd.	3 9/16	1/4	1.6

DATA SHEET, TEST BAKER
(10) DD-419, WAINWRIGHT

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
10-1	(V)	External, Gun Deck, Stbd.	1 5/16	0	-0.8
-2	(P)	External, Gun Deck, Stbd.	2 1/16	1/4	1.0
-3	(P)	External, Gun Deck, Aft	2 5/16	1/4	1.1

DATA SHEET, TEST BAKER
(11) IX-300, PRINZ EUGEN

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
11-1	(P)	Turret B, Gun Room	2 3/16	3/16	1.2
-2	(V)	Turret B, Gun Room	1 1/16	0	-0.7
-3	(P)	External, 05 Level, Stbd.	Flooded		-
-4	(P)	External, 07 Level, Fwd.	5 5/8	3/16	3.1
-5	(P)	External, 07 Level, Fwd.	5 13/16	5/16	3.2

DATA SHEET, TEST BAKER
(12) BB-34, NEW YORK

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) Water	Oil	PRESSURE lbs/sq.in.
12-1	(P)	Turret No. 5, Gun Chamber	2 1/4	1/2	1.2
-2	(P)	External, Main Director Level	7 9/16	9/16	4.3
-3	(P)	External, Main Director Level	Upset		-
-4	(V)	External, Main Director Level	Upset		-
-5	(P)	External, Covered Bridge, Aft.	8 13/16	5/16	5.0

DATA SHEET, TEST BAKER
(13) BB-36, NEVADA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
13-1	(P)	Gun Mount, Stbd., Aft.	4 15/16	3/16	2.7
-2	(P)	Gun Mount, Stbd.,Fwd.	1 3/8	1/4	0.8
-3	(P)	External, AirFwd.Level	10 3/8	0	-
-4	(V)	External, AirFwd.Level	2 3/8	3/16	-1.6
-5	(P)	Turret No.2,Officer's Booth	2 1/8	3/8	1.2

DATA SHEET, TEST BAKER
(14) BB-33, ARKANSAS

STATION	TYPE OF GAGE	COMPARTMENT	REMARKS
14-1	(P)	Turret No. 2, Gun Chamber, Right	SHIP SUNK IN TEST BAKER
-2	(V)	Turret No. 2, Gun C[illegible]mber, Right	
-3	(P)	Fire Room No. 1	
-4	(P)	Fire Room No. 1	
-5	(P)	External, Secondary Fwd. Level	

DATA SHEET, TEST BAKER
(15) CV-3, SARATOGA

STATION	TYPE OF GAGE	COMPARTMENT	REMARKS
15-1	(P)	Hangar Deck, Aft.	SHIP SUNK IN TEST BAKER
-2	(P)	Gun Mount No. 5	
-3	(V)	External, Flag Bridge	
-4	(P)	External, Flag Bridge	
-5	(P)	Flight Deck, Plane Interior	

DATA SHEET, TEST BAKER
(16) CA-24, PENSACOLA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
16-1	P	Engine Room, C-1	1/2	3/8	0.3
-2	P	Engine Room, C-1	Broken		-
-3	P	Fire Room, B-1	Broken		-
-4	V	Fire Room, B-1	Broken		-

DATA SHEET, TEST BAKER
(17) ex-Jap BB, NAGATO

STATION	TYPE OF GAGE	COMPARTMENT	REMARKS*
17-1	P	Turret No. 4, Gun Room	
-2	P	Turret No. 4, Gun Room	
-3	P	External, 9th Superstructure Deck	
-4	V	External, 11th Superstructure Deck	
-5	P	External, 11th Superstructure Deck	
-6	P	External, 11th Superstructure Deck	
-7	P	External, 11th Superstructure Deck	

* SHIP SUNK IN TEST BAKER

DATA SHEET, TEST BAKER
(18) BB-38, PENNSYLVANIA

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	READING (inches) OIL	PRESSURE lbs/sq.in.
18-1	P	Turret No.4, Officer's Booth	1	3/8	0.5
-2	P	Turret No.4, Officer's Booth	3/4	3/8	0.4
-3	V	Main Battery Director Level	Broken		-
-4	P	Main Battery Director Level	15/16	1/8	0.5
-5	P	Main Battery Director, Aft.	7/16	3/16	0.3

DATA SHEET, TEST BAKER
(19) CA-25, SALT LAKE CITY

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
19-1	P	Fire Room, B-1	3/8	1/4	0.3
-2	P	Fire Room, B-1	3/16	0	0.2
-3	P	External, Emergency, Port	2	3/8	1.1
-4	V	External, Emergency, Port	1 1/4	3/8	-1.0
-5	P	External, Emergency, Stbd.	3 15/16	3/16	2.2

DATA SHEET, TEST BAKER
(20) CVL-22, INDEPENDENCE

STATION	TYPE OF GAGE	COMPARTMENT	READING (inches) WATER	OIL	PRESSURE lbs/sq.in.
20-1	P	Burned Out Compartment Aft.	Broken		-
-2	P	Burned Out Compartment Aft.	Upset		-
-3	P	Engine Room, B-2	Left		-
-4	V	Cabin 0216	11/16	1/8	-0.5
-5	P	Cabin 0216	5/8	7/16	0.3

PART II - EXAMINATION OF EXTERNAL PRESSURES

Introductory

Although this report includes only a few measurements of external pressure, the examination of external pressures is of paramount interest to the present purpose since the internal pressures are preferably to be studied in terms of external pressures. At the present writing, the principal body of data concerning external pressures are not completely analyzed and assessed. Considerable concern has been felt as to whether mechanical gauges located on target vessels will measure a pressure free from distortion arising from reflections and from dynamic pressure changes associated with possible flow in the neighborhood of the target vessels. In order to establish a pressure distance relationship, the point of departure has been taken at a range where the external pressure measurements of this report and of other reports merge. At this range (2000 yds) a figure for the hydrostatic (side-on) pressure is determined upon, giving perhaps greater weight to the pressure measurements of this section, which are of such a nature that it is felt that they are truly hydrostatic pressures. With this figure for the pressure, a TNT equivalent tonnage is determined, and to be consistent with focussing attention upon the exact definition of the pressure being considered, the pressure distance relationship which will subsequently be used is that which is calculated from this TNT equivalent tonnage. It is noted that this treatment does not result in any violent disagreement with direct pressure measurements, and that a prerequisite to a further refinement is a more extensive study of all the pressure measurements in order to assess more rigorously the exact significance of these measurements. Lest unwarranted significance be attached to a figure for TNT equivalent tonnage, it is pointed out here that it is the opinion of this group that the general body of pressure measurements admit of uncertainties of 10 to 15% which amount to uncertainties of 30 to 50% in determination of TNT equivalent tonnage.

In making the approach described above - i.e., to adhere to a consistent and uniform definition of pressure - certain considerations concerning the physics of shock waves are set forth to refresh the background information

The theory of the blast wave from an ordinary explosive, such as TNT, has been developed to a point where the complete characteristics of the blast wave can be specified for any range d when there is available an accurate measurement of peak hydrostatic pressure at some one range d_o.

The theory that is available for the blast wave from TNT is in many respects equally applicable to the blast wave from detonation of an atomic bomb in air. An example of exact correspondence between the physics of the blast wave from TNT and the physics of the blast wave from an atomic bomb is furnished by the Rankine-Hugoniot equations of state which define the relations between the peak hydrostatic pressure at any given range d_1, and all of the other quantities which considered together completely define the wave front at this assigned range d_1.

The Rankine-Hugoniot equations of state tell us that if the peak hydrostatic pressure is known at some given range d_1, a unique value for each of the following quantities can immediately be obtained for this same range d_1.

(1) The temperature rise of the shock front above temperature of the undisturbed atmosphere.

(2) The density of the shock front as a multiple of the density of the undisturbed atmosphere.

(3) The rate of propagation of the shock wave front, called shock wave velocity, as a multiple of the velocity of sound in the undisturbed atmosphere.

(4) The velocity of a plane normal to direction of propagation of the shock wave, and across which plane the rate of transfer of mass is zero, called the mass velocity of the shock front, as a multiple of the velocity of sound in the undisturbed atmosphere. (Mass velocity is the velocity of an imaginary piston which is moving with the shock wave at a velocity somewhat less than the shock wave velocity.)

Discrete values for the foregoing four quantities can be obtained by reference to published tables for these quantities as a function of the ratio P_2/P_1, where P_1 is the absolute pressure of the undisturbed atmosphere, and where P_2 is the absolute hydrostatic pressure of the shock wave front. An exact set of values for the properties of shock waves in air may be found in Table 16-1 of reference (1).* An advantage of using the foregoing tabulation is that the values have been corrected for change in the heat capacity of air with change of absolute termperature.

The principal interest that the four quantities listed above has is that the quantities are sufficient for calculating a unique value of peak stagnation pressure for each value of peak hydrostatic pressure.

* A list of the references is given at the end of Part II, on page 64.

Stagnation pressure is the quantity which corresponds to what in the Bernoulli equation for fluid flow is called dynamic pressure. The Bernoulli equation holds accurately only for flow of a medium which can be considered to be incompressible. At the velocities encountered in shock wave theory, the atmosphere can not be considered to be an incompressible medium, and ~~hence~~ in this region of flow the theory such as that developed in section 97 of reference (2) must be used.

When one has determined the peak hydrostatic pressure at any given range d_1 and the peak stagnation pressure at this same range d_1, one has available all of the blast wave information that is necessary for determing the peak loading that a given, simple, rigid structure will be called upon to take, for the following two conditions of considerable interest:

(a) A thin plane parallel to the direction of propagation of the blast wave. The peak loading is the peak hydrostatic pressure.

(b) A plane normal to direction of propagation of the blast wave, and of small size such that steady-state flow past the obstacle has been established at the instant of interest. The peak loading occurs at the stagnation point of the plane, and is equal to the peak hydrostatic pressure plus the peak stagnation pressure. At any other location along the obstacle, the peak pressure will be less than the foregoing total pressure, by an amount which is a function of rate of flow at the location.

When one is obliged to consider action of a blast wave on a surface of large extent, such as surface of the lagoon at Bikini, it is not possible to ignore the action in the interval before steady-state flow past the obstacle has been established. (In the case of an infinitely extended surface such as the ground level, flow past the obstacle is never established, all of the action being reflection). Reflection is a different action from stagnation, the former being always the larger of the two.

The Rankine-Hugoniot equations of state that are used for determining the characteristics of a shock front that is traveling through free space are sufficient for determining the characteristics of a reflected shock front at a plane of head-on reflection. What one does is to consider the shock front as a new atmosphere, in which a piston of mass velocity u^1 is moving, with u^1 equal to -u of the original shock front. (This makes the new mass velocity equal to zero relative to a stationary point on the ground.) Knowledge of this new mass velocity is sufficient for determining the other quantities of the reflected shock front, such as the quantity of reflected peak hydrostatic pressure.

If one has accurately measured the peak hydrostatic pressure at some assigned range d_0 for an air burst of an atomic bomb, one can estimate with good precision what peak hydrostatic pressure must have existed at any other range d_1 - providing that the extrapolation in either direction is not carried too far, such as up to the atomic bomb itself.

The theory by which one is enabled to extrapolate peak hydrostatic pressure from one range d_0 to any other range d_1 is the theory which states that for any weight of charge whatsoever of TNT, the blast wave produced in free space scales exactly with the dimensionless quantity $R/(W/\sigma)^{1/3}$ where R is the air-line distance from the charge, where W is the weight of the spherical bare charge of TNT, and where σ, which is assumed to be constant, is the specific weight of TNT. As stated above, this scaling factor for dependence on weight is considered to hold for any weight of TNT whatsoever, whether the weight being considered is 1.0 pound or 40,000,000 pounds.

When 40,000,000 pounds of TNT are detonated in free space, the peak hydrostatic pressure which may be expected at 2000 yards is readily found to be 3.05 pounds per square inch gauge. This knowledge of what pressure to expect is obtained from experiments with small charges of TNT, from which test results it is reported that when the value of $R/W^{1/3}$ is 17.5, the value of peak hydrostatic pressure is the figure given above. This value for peak hydrostatic pressure is the value obtainable by interpolation from the data presented in reference (3).

As a check on the accuracy of the foregoing value for peak hydrostatic pressure, it is reassuring to note that the value agrees precisely with the independently obtained value plotted in Figure 11 of reference (4) for a half-pound charge.

The foregoing value of 3.05 pounds per square inch as the peak hydrostatic pressure at 2000 yards for detonation of 20,000 tons of TNT happens to agree with the best determination of peak hydrostatic pressure at 2000 yards in Test ABLE. Thus one can state that as referred to detonation of a bare charge of TNT in free space, the TNT equivalent of the Test ABLE burst is 20,000 tons. It is interesting to note that this particular figure happens to coincide with the publicly reported figure of 20,000 tons as the TNT equivalent of an atomic bomb air burst.

The foregoing figure of 20,000 tons as the TNT equivalent of the Test ABLE burst is the figure for comparison with TNT detonated in free space. The comparison can be refined by having the TNT equivalent refer to detonation of TNT in the actual non-free space of the Test ABLE burst.

As determined by Icaroscope measurement, the height of detonation, h, in Test ABLE was approximately 500 feet above surface of the lagoon. As previously stated, the best determination of peak pressure for 2000 yards from actual center of burst is 3.05 pounds per square inch. By interpolation in Figure 36 of reference (4), the value of W which gives a peak pressure of 3.05 pounds per square inch at ground level for values of 6000 feet and 500 feet for d and h respectively is 14,100 tons. The values of $d/W^{1/3}$ and $h/W^{1/3}$ are 19.7 and 1.64 respectively.

Knowing the equivalent weight of TNT and the height of burst, as given above, one can immediately plot a peak hydrostatic pressure-distance graph for the Test ABLE burst. The plot consists of transferring directly the data of Figure 36 of reference (4) using the appropriate values of charge height and charge weight.

When the peak pressure-distance graph of an atomic bomb burst has been established, the pressure-time graph for the positive phase of the blast wave can be developed, from theory. The computation consists of using the Rankine-Hugoniot conditions of state and the equations of hydrodynamics to calculate for each range d_1 a unique value for the so-called time constant of the blast wave. The definition of this particular time constant is that it is the negative reciprocal of the initial logarithmic time derivative of the pressure-time curve. The method of computation is explained in reference (5).

Having determined values for the foregoing time constant as a function of range from center of burst, one can proceed further, and develop the entire positive phase of the pressure-time graph for any range d_1, from knowledge of the measured pressure-time graph at some one range d_0.

The base line of the foregoing pressure-time graph is the duration of the positive phase of the blast wave, and the integral of the graph is the positive impulse of the blast wave. Both of these quantitives are necessary information for ship designers in their computing how much blast a given ship structure can be expected to take without suffering damage.

When one has obtained the hydrostatic pressure-time graph at any given location it is a simple matter to go one step further, and derive the total pressure-time graph for the given location.

Comparison of Calculated and Measured Values of Peak Pressure, Test ABLE

In the plot of Figure 6 peak hydrostatic pressure and peak total pressure are plotted against the ratio $d/W^{1/3}$, where d is the horizontal distance from center of burst in feet, and where W is the TNT equivalent of the Test Able burst at the height of 500 feet. The derivation of 28,200,000 pounds as the indicated value of W has already been explained. The accuracy of fit of values thus calculated to the experimental values is shown by the amount of agreement between the heavy solid lines of Figure 6, and the experimental points for Bureau of Ships data together with the dashed line for plot of Bureau of Ordnance (W.G. Penney report, reference (5)) smoothed data.

Inspection of Figure 6 shows that the agreement between calculated values and measured values is excellent. This excellent agreement between theoretical and measured values is proof that each of the types of gauge used gave results which are quantitatively significant. The types of gauge considered in Figure 6 are principally three, namely, the standard station barograph as used in aerological work, the peak pressure (Pyrex) gauge developed by the Bureau of Ships, and the foilmeter employed by the Bureau of Ordnance and the gasoline cans of Dr. Penney. The probable reasons for the slight discrepancies of Figure 6 between calculated values and measured values are discussed later.

An explanation of how the graph of Figure 6 for hydrostatic pressure in the Mach stem has been derived will now be given. The method of determining pressure at the ground when the free-field incident side-on (hydrostatic) pressure is known is explained in reference (6). For the pressure range of 3.05 to 100 pounds per square inch gauge, the values of free-field hydrostatic pressure used are the values of reference (3).

In Figure 6, the continuation of the graph for peak hydrostatic pressure from 3.05 to 0.1 pounds per square inch is the best fit to the data which results in an exponent of 1.48 for dependence on range. The empirical value commonly chosen for this exponent is the round number 1.5, as used, for instance, in reference (7).

In Figure 6, the graph of peak total pressure was computed from the theory of stagnation pressure developed in section 97 of reference (2). However, the equation actually used for calculation of stagnation pressure contains one more term in the expansion than the

number of terms printed in the foregoing reference. Using the same notation as in reference (2), this additional term of the expansion is plus $1/40\,(w_0/c)^4$. For shock waves in air, the density to use in the foregoing equation for peak stagnation pressure is the absolute density of the shock front; the velocity to use w_0 is the mass velocity of the shock front, and the velocity to use for c is that for the velocity of sound under the pressure and density state of the shock front. When the foregoing substitutions are made, the equation for stagnation pressure exactly applies to steady-state flow of shock waves in air.

Comments on the Experimental Data

Weather Station Data

Figure 7 shows a composite plot of all peak pressure measurements at the Bureau of Ships stations on Bikini, Enyu, Airukiiji, and Aomen. This composite plot is reduced to the scale of the Test Able position pressure measurements by applying to all other measurements the mean percentage ratio which those measurements had relation to the Test Able position pressure, choosing these ratios so as to bring about the best agreement for the largest cluster of measurements, viz; on Enyu. However, the internal consistency is good throughout, and within the expected probable error of the recording.

The distances from the explosion used are as follows: Bikini 6560 yds., Enyu 10540 yds., Airukiiji 14260 yds., and Aomoen 14740 yds.

Peak Pressure (Pyrex) Gauge Data

Figure 6 shows that the agreement between peak pressure (Pyrex) gauge measurements and values calculated as described above is very good. For the most part, the disagreements are felt to be of the order of accuracy of the various gauges.

It is interesting to note in Figure 6 that the reading for the destroyer WAINWRIGHT lies slightly below the calculated graph, while the reading for the troop transport BRACKEN lies slightly above the calculated graph. The reason for this slight difference with type of ship is not known, but may be associated with the fact that the gauges on troop transports at the sky-lookout level were under canvas covers. This same difference with type of ship was noted in Test Baker.

Part of the lack of exact agreement in Figure 6 between Pyrex gauge measurements and the corresponding calculated val-

ues possibly can be attributed to presence of a slight amount of stagnation pressure at the gauge locations, due to geometry of the ship in relation to the blast. However, the stagnation pressure at distances beyond 2000 yards is negligible for all but very exact analysis. The head-on reflected pressure at 2000 yards is large relative to stagnation pressure at this range, but for obstacles of comparatively small presented area, the duration of head-on reflected pressure is very brief. The response time of the Pyrex gauges is believed to be such that they would not register head-on reflected pressure at sky-lookout levels.

As a matter of incidental interest, the Pyrex gauge readings for stations 7-7 and 18-1 are shown in Figure 6. These stations refer to officer's wardroom of the BRULE and gun room of turret B of the Prinz Eugen respectively. The readings are marked by crosses rather than circles to call attention to the fact that these stations by being in compartments may be considered to be only semi-external locations.

Foilmeter Data

Figure 6 contains a plot of the smoothed data for Bureau of Ordnance foilmeter measurements and gasoline can gauge measurements. The data used extend from 2000 yards in to 360 yards, and contain all of the smoothed data of reference (5) for Test Able except for the value of zero yards range, directly under the bomb.

The agreement at the extremes of the foilmeter smoothed data, with the computed values, is interesting. At 2000 yards range, the smoothed and calculated values are 3.0 and 3.05 pounds per square inch respectively. The range required to reach a blast pressure of 100.0 pounds per square inch gauge are 360 and 370 yards respectively. Agreement of this kind may for most purposes be considered to be perfect.

It is in the interval between 2000 yards and 360 yards range that a slight discrepancy appears between the foilmeter smoothed data and the calculated values of Figure 6. It is true that the foilmeter data drawn upon here are from an early report; more rigorous examination of those data may refine the agreement. The fact that the foilmeter data lie generally above the hydrostatic pressure curve suggests that the foilmeters may have responded in some degree to stagnation pressures over and above the strictly hydrostatic pressure. In any event the scatter in the foilmeter data is such that the curve of Figure 6 is a not unsatisfactory representation of the hydrostatic pressure, especially if the foilmeters are in fact influenced by stagnation pressures,

and this curve has been used as the pressure distance relationship for Test Able. For ready reference, a tabulation of these pressures is given in Table I. Similarly, Table II tabulates values of the following properties of the shock front: temperature rise, density, mass velocity, and velocity of propagation. At close ranges it may be necessary to take account of the interaction between radiation and molecular pressure, when the data of Figure 6 are meant to refer to an actual atomic bomb burst. As explained before, these are particular values calculated on the basis of the equivalent of 14,100 tons of TNT at 500 feet height of burst. In Table II, the velocity of 1152 is the velocity of sound at Bikini Atoll at time of Test Able, in feet per second, and the specific weight of 0.0721 is the specific weight of air at Bikini Atoll at time of Test Able, in pounds per cubic foot. These two values for atmospheric air were calculated from weather station measurements taken at Bikini, Enyu, Airukiiji, and Aomoen at the time stated.

Comparison of Calculated and Measured Values of Peak Pressure, Test Baker

In Test Baker, the principal body of pressure measurements derive from the foilmeters and gasoline cans (at close ranges), the Pyrex gauges (at farther ranges), and the barographs (at distant ranges). The barograph and Pyrex gauge data are given in Figure 9. The tendency toward high readings for those gauges on NIAGARA, BLADEN, and BANNER may be due to the proximity of the smoke stack, or to the fact that they were under a canvas awning. At the ranges under 2000 yards the Pyrex gauges are significantly below the line taken to represent the faired data. This tendency of these gauges is not understood; it may be influenced by an upward direction of the blast at the shorter ranges, the screening effect of water vapor, or the effect of shock disturbances of the gauges on the nearer ships.

With the exception of the BRACKEN, every Pyrex gauge reading of Figure 9 was checked by another reading on the same ship; the checks all agreed within 0.1 pound per square inch.

The best value of pressure has been taken as 1.92 pounds per square inch at 2000 yards. By the data and theory of references (4) and (6), this value results in a free-field TNT equivalent tonnage of 8060 tons, or 4000 tons exploded at the surface of the lagoon. The heavy curve of Figure 8 is calculated on this basis. The circumstances of the initiation of the air borne shock wave are such that figures for a TNT equivalent tonnage have no real significance in relation to the bomb except to say that the measured values are as though such a TNT charge had been detonated.

It is seen that the agreement between the curve and the calculated and the measured data is quite good. Between 2000 yds. and 15,000 yds, the variation in pressure with distance is as the 1.48 power of the reciprocal of the range, just as in Test Able.

The gauges on PRINZ EUGEN are included here as a matter of interest. These gauges were located in a large pocket in the superstructure of the ship frontal to the blast, and it is seen from Figure 8 that these gauges were significantly influenced by the reflections.

Table III tabulates values of the various pressures, and Table IV gives values of the various quantities pertaining to the shock front. These are based upon the TNT equivalent tonnage already described. The figures in parentheses are regarded as quite doubtful, they bring for close ranges where it can not be assumed that this conception of TNT equivalent will adequately describe the conditions of the submerged atomic bomb explosion.

Peak Vacuum, Tests Able and Baker

Figure 10 shows a plot of the three Pyrex gauge measurements of external peak vacuum in Test Able, together with a plot of the four barograph measurements of external peak vacuum.

Inspection of Figure 10 shows that the graph for external peak vacuum as based on the Pyrex gauge measurements lies slightly higher than the corresponding graph as based on the barograph measurements. The values for ratio of external peak vacuum to external peak pressure are 0.46 and 0.56 for the barograph measurements and the Pyrex gauge measurements respectively. The peak vacuum at 2000 yards thus lies somewhere in the range of 1.4 to 1.7 pounds per square inch.

The correct explanation for the lack of better agreement between the two foregoing sets of data is not known, but the discrepancy of only 0.3 pound per square inch at 2000 yards can not be considered serious, when the several possibilities for a slight difference in reading between the two types of gauge are considered. For instance, the exponent of 1.48 used for extrapolating the barograph measurements from Bikini in to 2000 yards may not hold quite as well for peak vacuum or for peak pressure. A source of possible error in the Pyrex gauge vacuum readings is the known temperature susceptibility of the Pyrex vacuum gauge. If the Pyrex vacuum gauges had been read when the gauges were at a temperature of only 3.8 degrees F below the ambient temperature of 85.2 degrees F which existed at the time of Test Able, an error of plus 0.3 pound per square inch would have been introduced for each gauge.

However, it is believed that the difference in temperature between time of test and time of reading was less than the required 3.8 degrees F - unless possibility of the gauges being in direct sunlight at time of Test Able was important.

In view of the findings of Test Baker concerning agreement between barograph readings of peak vacuum and Pyrex gauge readings of peak vacuum, it is recommended that the peak vacuum in Test Able at 2000 yards be considered to be 1.4 pounds per square inch, which is the figure indicated by the barograph readings of peak vacuum in Test Able. This figure will make the readings of Tests Able and Baker mutually consistent.

The Test Baker vacuum measurements are plotted in Figure 11. These measurements follow equally well the empirical dependence upon range determined from Test Able. Further, the ratio between peak pressure and peak vacuum is consistent throughout for Test Able and Baker. At 2000 yards, applying this ratio as determined in Test Able to the pressure measurements of Test Baker results in a predicted value of peak vacuum for Test Baker of 0.87 pounds per square inch; the faired experimental value is 0.84 pounds per square inch.

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(8) OSRD Report No. 4356, "The Calculation of the Time Constant and the Positive Impulse from the Peak Pressure-Distance Curves of Blast Waves in Air with an Application to Cast TNT", by J.G. Kirkwood and S.R. Brinkley, Jr., 25 November 1944.

TABLE I, PEAK PRESSURE VALUES, TEST ABLE

RANGE, HORIZONTAL, YARDS	HYDROSTATIC PRESSURE, GROUND LEVEL,	STAGNATION PRESSURE, GROUND LEVEL,	TOTAL PRESSURE GROUND LEVEL,	HEAD-ON REFLECTED PRESSURE GROUND LEVEL
	lbs./sq.in.	lbs./sq.in.	lbs./sq.in.	lbs./sq.in.
d	p	q	p + q	pf
0				
370	100.0	178.9	278.9	570.0
400	84.0	131.3	215.3	400.3
500	48.5	48.0	96.5	190.0
600	31.2	21.6	52.8	105.0
700	22.0	10.7	32.7	67.0
800	16.4	6.0	22.4	46.6
900	12.8	3.7	16.5	35.0
1000	10.3	2.4	12.7	26.9
1100	8.6	1.7	10.3	21.5
1200	7.3	1.2	8.5	17.6
1300	6.3	0.9	7.2	14.8
1400	5.5	0.7	6.2	12.7
1500	4.9	0.5	5.4	11.0
1600	4.4	0.45	4.85	9.7
1700	3.95	0.37	4.32	8.6
1800	3.59	0.30	3.89	7.8
1900	3.30	0.25	3.55	7.0
2000	3.05	0.20	3.25	6.4

TABLE II, SHOCK FRONT VALUES, TEST ABLE

RANGE HORIZONTAL, YARDS d	VELOCITY OF SHOCK FRONT, RATIO TO 1152 fps	MASS VELOCITY OF SHOCK FRONT, RATIO TO 1152 fps	DENSITY OF SHOCK FRONT, RATIO TO 0.072[illegible] lbs./cu.ft.	TEMPERATURE RISE OF SHOCK FRONT, DEGREES FAHRENHEIT
0				
370	2.585	1.843	3.530	643.
400	2.405	1.672	3.275	550.
500	1.953	1.200	2.610	347.
600	1.685	0.913	2.180	243.
700	1.509	0.707	1.882	175.
800	1.400	0.567	1.687	137.
900	1.321	0.468	1.552	111.
1000	1.265	0.397	1.456	92.
1100	1.224	0.339	1.380	78.
1200	1.193	0.296	1.327	67.
1300	1.169	0.262	1.286	59.
1400	1.148	0.233	1.252	53.
1500	1.133	0.210	1.226	47.
1600	1.120	0.190	1.204	42.
1700	1.109	0.173	1.184	38.
1800	1.099	0.158	1.168	34.
1900	1.092	0.144	1.153	31.
2000	1.085	0.132	1.140	29.

TABLE III, PEAK PRESSURE VALUES, TEST BAKER

RANGE, HORIZONTAL, YARDS. d	HYDROSTATIC PRESSURE, GROUND LEVEL, lbs./sq.in. p	STAGNATION PRESSURE, GROUND LEVEL, lbs./sq.in. q	TOTAL PRESSURE, GROUND LEVEL lbs./sq.in. (p+q)	HEAD-ON REFLECTED PRESSURE, GROUND LEVEL lbs./sq.in. pf
400	(37.0)	(31.3)	(68.3)	(132.0)
500	(21.6)	(10.3)	(31.9)	(65.5)
600	14.8	5.0	19.8	41.5
700	11.0	2.8	13.8	28.8
800	8.5	1.7	10.2	21.2
900	6.9	1.1	8.0	16.6
1000	5.8	0.8	6.6	13.5
1100	5.0	0.6	5.6	11.3
1200	4.3	0.4	4.7	9.5
1300	3.8	0.3	4.1	8.3
1400	3.3	0.2	3.5	7.0
1500	3.0	0.2	3.2	6.3
1600	2.7	0.1	2.8	5.6
1700	2.4	0.1	2.5	5.0
1800	2.22	0.10	2.32	4.6
1900	2.07	0.08	2.15	4.2
2000	1.92	0.06	1.98	3.7

TABLE IV, SHOCK FRONT VALUES, TEST BAKER

RANGE HORIZONTAL, YARDS. d	VELOCITY OF SHOCK FRONT, RATIO TO 1152 fps	MASS VELOCITY OF SHOCK FRONT, RATIO TO 1152 fps	DENSITY OF SHOCK FRONT, RATIO to 0.0721 lbs./cu.ft.	TEMPERATURE RISE OF SHOCK FRONT, DEGREES FAHRENHEIT.
400	(1.775)	(1.015)	(2.330)	(278.)
500	(1.502)	(0.692)	(1.865)	(172.)
600	1.364	0.525	1.626	125.
700	1.281	0.417	1.482	97.
800	1.223	0.340	1.382	77.
900	1.184	0.286	1.320	64.
1000	1.156	0.248	1.270	56.
1100	1.136	0.217	1.235	48.
1200	1.118	0.187	1.200	42.
1300	1.105	0.167	1.177	37.
1400	1.092	0.146	1.157	33.
1500	1.084	0.134	1.140	30.
1600	1.076	0.122	1.126	27.
1700	1.068	0.109	1.113	24.
1800	1.063	0.101	1.105	22.
1900	1.059	0.095	1.098	20.
2000	1.057	0.088	1.091	19.

PART III, INTERNAL PRESSURE MEASUREMENTS

This part of the report is concerned with determination of internal peak pressure in Test Able as a function of range, for each of three main types of ship, and for each of five main types of ship compartment. The treatment will relate these internal pressures to the external pressures as determined in Part II preceding.

INTERNAL PEAK PRESSURE AS A PER CENT OF LOCAL EXTERNAL PEAK PRESSURE

Figures 12, 13, 14 and 15 show a plot of Pyrex gauge measurements of internal peak pressure in Test Able. These measurements of internal, positive peak pressure are all such values obtained in Test Able for the five main types of ship compartment shown. The total number of values plotted is 118. In these figures, the internal peak pressure has been expressed as a per cent of the local external peak pressure.

When internal peak pressure is plotted as a per cent of the local external peak pressure, there is no observable dependence on range. Expressed in the language of statisticians, no significant regression with range exists in any of the five sets of data plotted in Figures 12-15 as grouped by type of ship compartment. This conclusion was tested by the required statistical computations. This important finding from the data does not necessarily mean that no dependence on range exists, but that whatever dependence may exist is minor in effect as compared with the effects of other variables, such as slight differences in ship construction from ship to ship, for a given type of ship and given type of ship compartment.

Discovery of the foregoing lack of dependence on range allows calculation of an average value for internal peak pressure as a per cent of the local external peak pressure. This calculation has been made for each of the five main types of ship compartment, of the enclosures. The results are tabulated in Table V.

Inspection of Table V shows that the change in average by going from one type of ship to another type of ship is extremely small, for a given type of ship compartment, but is not small in going from one type of ship compartment to another type of ship compartment. This observation allows calculation of an average value for all types of ship, for each of the five main types of ship compartment.

The local external peak pressures which have been used are the values given in Table VI. The pressure values of Table VI were obtained from the data of Part II of this report. The values of range for the 26 target vessels are the values considered most reliable as of January 1947.

The values tabulated in Table V differ somewhat from the values reported in the interim report of this group. The improved accuracy is mostly due to use of the true peak pressure-distance graph of Test Able, in place of the so-called standard graph previously available. The difference in the two foregoing graphs is illustrated in Figure 16.

STATISTICAL EXAMINATION OF DATA

The averages given in Table V are plotted in Figure 17, and from each such point, the 50 per cent confidence band is drawn as determined for n observations per experimental point, where n is the actual number of observations made for determining the particular average. The value of n for each average is shown in Figure 17. The computation of each confidence band was made on the assumption that the distribution of individual determinations about the true average is a normal one, as the term "normal distribution" is understood by statisticians.

The meaning of any given confidence band of Figure 17 is that if the particular type of test were repeated any given number of times with always the same number n of observations per average, then in the long run, the averages so obtained would fall within the given confidence band 50 per cent of the time. For instance, if Test Able were repeated and 8 new observations of peak pressure in fire rooms of destroyers were obtained, at locations selected at random, the new average value for compartment peak pressure would have a 50:50 probability of falling within the band of values shown in Figure 17 for this particular type of compartment. The confidence band there shown covers the range of 23.5 ± 3.3 units.

From the data used in developing Figure 17, it is possible to compute the confidence bands for any number of new observations per average. The confidence band for any number X of new observations per average is given by $y \pm \Delta y \sqrt{n/x}$, where for fire room destroyers the values determined in Test Able for y, Δy, and X are 23.4, 3.3, and 8 respectively. Figure 18 shows the effect of utilizing the foregoing theory to find the confidence bands for 10 observations per average, for each type of compartment studied. The advantage of

converting Figure 17 into Figure 18 is that the new chart shows at a glance the comparative variability of the original sets of data. For instance, Figure 18 shows that when fire rooms are considered, the scatter of data for destroyers, capital ships, and transports is very nearly the same, the half-widths of confidence band being 2.9, 2.7, and 3.0 respectively. This close agreement of the data suggests that a half-width of confidence band of between 2.7 and 3.0 for 10 observations per average is representative of fire rooms in general, and reflects the inherent variability of such data. The inherent variability arises from difference in orientation of the ships with respect to the burst; differences in construction and compactness of fire rooms from ship to ship of the same type, and also from ship to ship of different type; differences in the type of boiler casing installed; differences in peak pressure from point to point in a given compartment; differences due to systematic errors of the peak pressure gauge itself; possible differences due to minor dependence on distance from burst; etc. Clearly, an important part of the responsibility of presenting the Test Able data on compartment peak pressure is to evaluate accurately, by statistical methods, the degree of inherent variability of the various sets of data obtained.

It is important to appreciate that the variability shown in Figure 18 is almost entirely variability due to factors other than features related to the gauge itself. A comparison between the variability of the gauge and the variability of readings obtained with the gauge is shown in Figure 19. How the 50 per cent confidence band for the gauge itself has been estimated will now be explained. The gauge was always read only to the nearest 0.1 pound per square inch. In Test Baker, a number of check readings were obtained from placing pairs of gauges either side by side, or external on the same ship. These check readings showed that two gauges so placed would read within 0.1 pound per square inch of each other virtually every time. Thus it is reasonable to believe that any one gauge would read the true pressure to an accuracy of $\pm$ 0.05 pound per square inch approximately 50 per cent of the time, or better. This means that as referred to the external peak pressure at 2000 yards in a Test Able burst (where the peak hydrostatic pressure is 3.05 pounds per square inch), an error of 0.05 pound per square inch in one reading would in the average obtained from 10 readings represent an error of 0.05/√10 pounds per square inch, which is an error of $\pm$ 0.5 per cent of local external peak pressure. This value of 0.5 per cent is the value shown in Figure 19 for the peak pressure gauge at 2000 yards, by itself. The corresponding value for 800 yards also is shown. These values compare with the value of 2.9 per cent shown for fire room of destroyers, as taken directly from Figure 19.

It is possible to show that a part of this variability for fire rooms is due to differences in the type of boiler casing installed. Of the observations for fire rooms, 13 were for ships having single cased boilers, and the remaining 8 were for ships having double cased boilers. The effect of segregating the observations by type of boiler casing is shown in Figure 20. A fire room with single cased boilers is one which has comparatively open fire doors, and hence is one which may be expected to develop somewhat higher peak pressure in the fire room than will a fire room which is protected, in this respect, by double cased boilers. This expectation is borne out by the new averages shown in Figure 20, these new values being 25.3 and 18.6 units for fire rooms with single cased and double cased boilers respectively, in place of the previous combined value of 23.5 units. That the difference uncovered is a significant one is shown by the fact that the confidence bands do not overlap. The foregoing value of 18.6 represents peak pressure that has come in mostly through ventilation ducts, and the difference between 25.3 and 18.6 presumably represents peak pressure that has come in mostly through fire doors.

It is interesting to compute the average peak pressure value for the combined fire room and engine room of transports on the assumption that this type of compartment is intermediate in characteristics between a fire room with double cased boilers, and a generalized engine room. The predicted value is obtained by averaging the value of 18.6 obtained from Figure 20 with the value of 8.2 obtained from Figure 18. The value of 13.4 so obtained compares with the measured value of 13.8 for this type of compartment. Agreement between the values is remarkably good, and gives an added reason for confidence in the separate values of average peak pressure.

The half-widths of confidence band associated with the foregoing values of 18.6 and 8.2 are 3.0 and 2.0 units respectively, for 10 observations per average. These values compare with 3.1 units as the corresponding half-width of confidence band for the average value of 13.8 mentioned above.

TABLE V. AVERAGE COMPARTMENT PEAK PRESSURE, TEST ABLE.

TYPE OF SHIP	Average Value for Compartment Peak Pressure, Per Cent of the Corresponding External Peak Pressure, For Type of Ship Compartment Indicated:				
	Fire Room	Fire and Engine Room:	Engine Room:	Wardroom and Cabin:	Berthing:
Destroyers	23	-	7	1	13**
Transports	-	14		2	13
Capital Ships	23	-	8	5**	14
All Ships	23	14	8	3	14

* Reading for Stations 23-2 disregarded, to avoid distortion of average.

** Reading for Station 15-7 disregarded, to avoid distortion of average.

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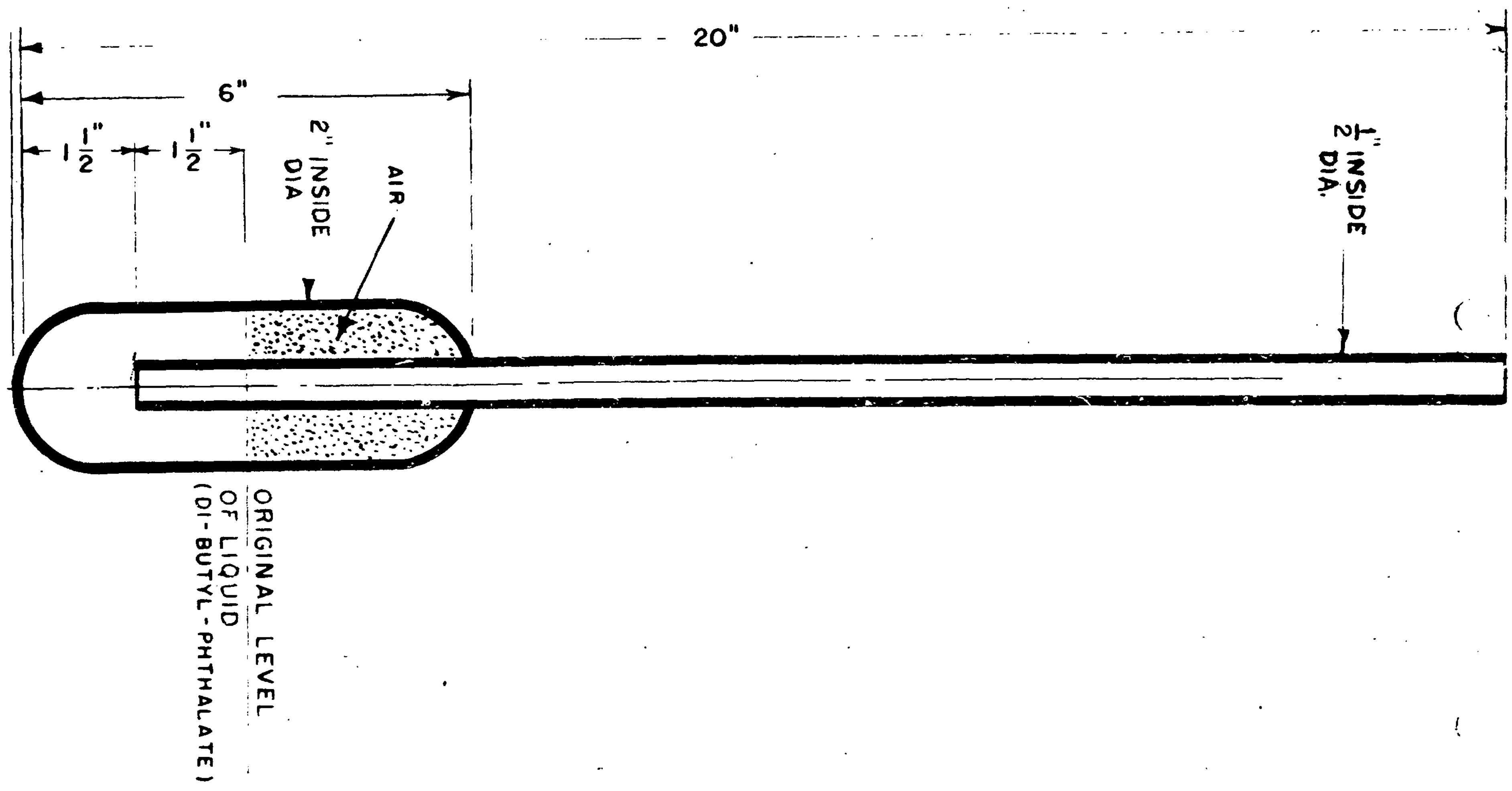
TABLE VI. TARGET SHIP EXTERNAL PEAK PRESSURE MIDSHIP SECTION:

NO.	TARGET SHIP, LISTED IN ORDER OF RANGE FROM CENTER OF BURST.	HORIZONTAL DISTANCE FROM CENTER OF BURST, YARDS.	EXTERNAL HYDROSTATIC PEAK PRESSURE lbs./sq.in.
(1)	APA 57, Gilliam	117.	-
(2)	SS 305, Skate	439.	66.0
(3)	CVL 22, Independence	633.	27.7
(4)	BB 36, Nevada	701.	22.0
(5)	BB 33, Arkansas	702.	22.0
(6)	DD 367, Lamson	767.	18.0
(7)	CA 24, Pensacola	805.	16.4
(8)	BB-JAP, Nagato	900.	12.8
(9)	CA 25, Salt Lake City	958.	11.3
(10)	DD410, Hughes	970.	11.0
(11)	DD 404, Rhind	1040.	9.6
(12)	APA 66, Brule	1050.	9.4
(13)	DD 390, Ralph Talbot	1203.	7.3
(14)	APA 60, Banner	1243.	6.8
(15)	IX - 300, Prinz Eugen	1308.	6.2
(16)	APA 65, Briscoe	1640.	4.16
(17)	BB 34, New York	1643.	4.15
(18)	BB 38, Pennsylvania	1645.	4.14
(19)	APA 71, Catron	1825.	3.50
(20)	APA 64, Bracken	2098.	2.80
(21)	DD 413, Mustin	2203.	2.60
(22)	DD 419, Wainwright	2212.	2.58
(23)	CV 3, Saratoga	2413.	2.24
(24)	DD 389, Mugford	2747.	1.83
(25)	APA 63, Bladen	2855.	1.73
(26)	APA 87, Niagara	3355.	1.37



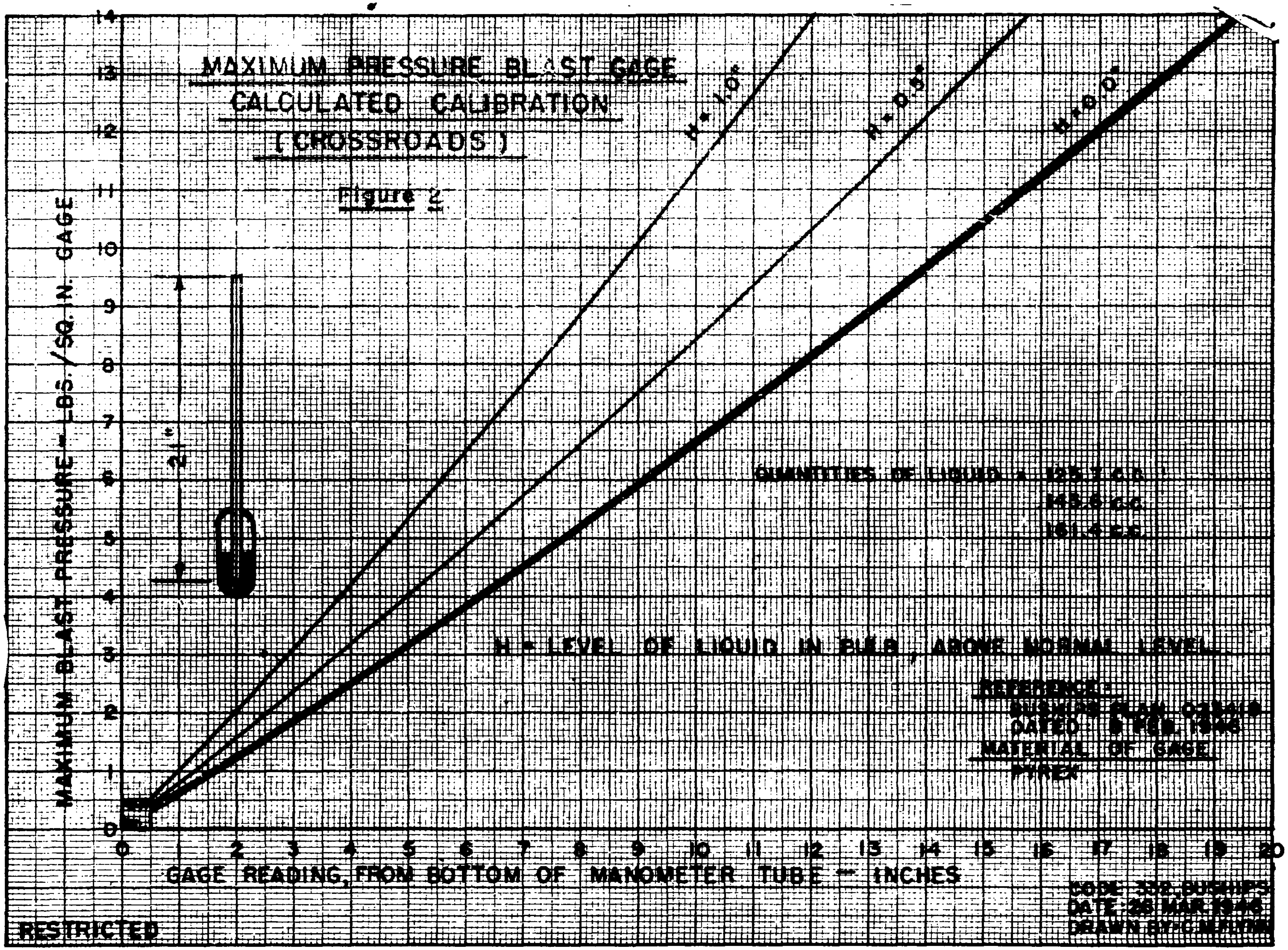
GAGE FOR MEASURING MAXIMUM PRESSURE FROM BLAST

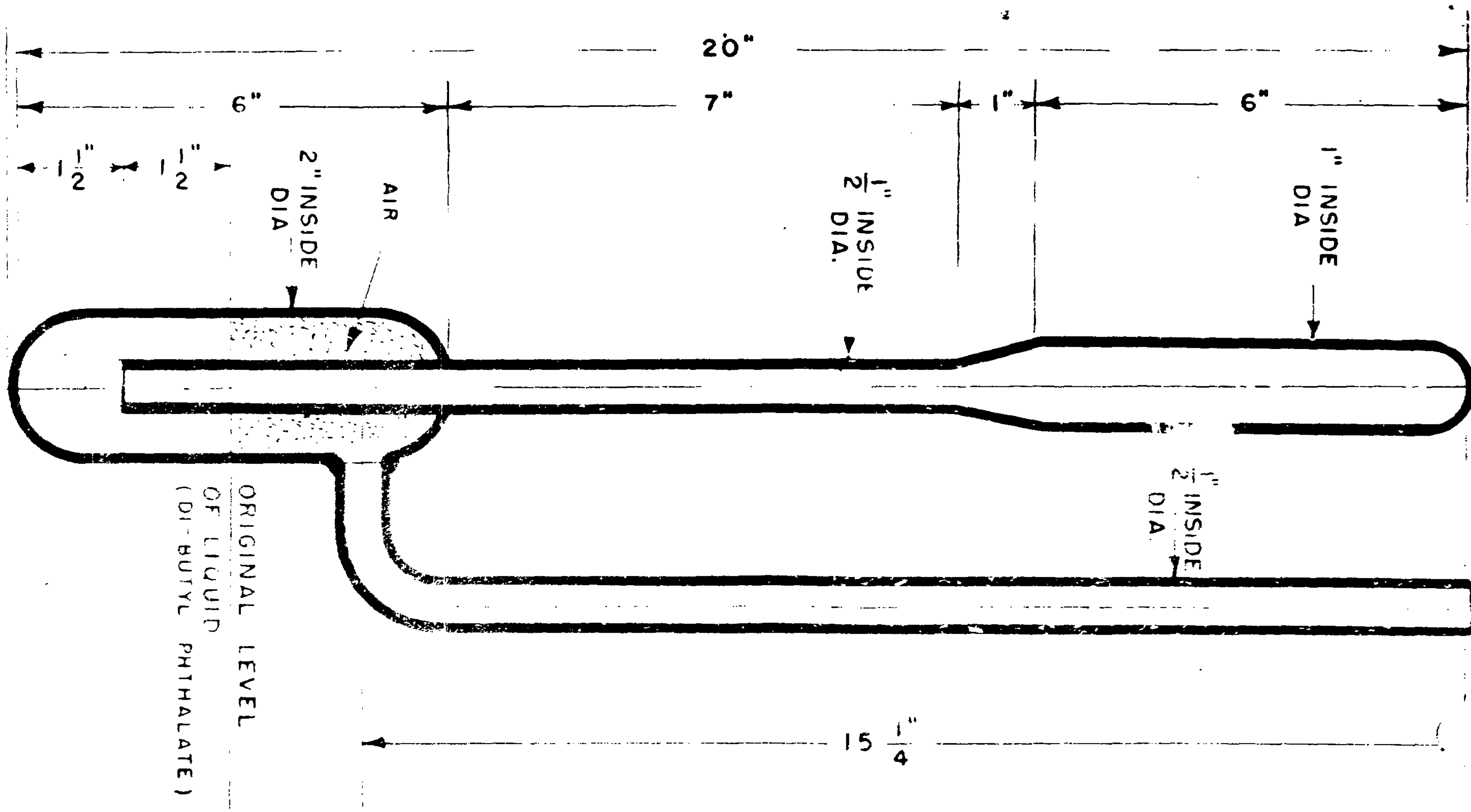
Figure 1

BUSHIPS DWG. NO. 023419

RANGE:
RESPONSE:

DATE: 8 FEB 1946
CODE 332
DRAWN BY: C.M. FLYNN


MAXIMUM PRESSURE BLAST GAGE
CALCULATED CALIBRATION
(CROSSROADS)
Figure 2
H = 1.0"
H = 0.5"
H = 0.0"
2 1/2"
QUANTITIES OF LIQUID
145.6 C.C.
161.4 C.C.
H = LEVEL OF LIQUID IN BULB, ABOVE NORMAL LEVEL
REFERENCE:
MATERIAL OF GAGE
PYREX
MAXIMUM BLAST PRESSURE — LBS./SQ. IN. GAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
GAGE READING, FROM BOTTOM OF MANOMETER TUBE — INCHES
CODE 332, BUSHIPS
RESTRICTED



GAGE FOR MEASURING MAXIMUM VACUUM FROM BLAST

Figure 3

RANGE: 0 TO 14.7 LBS SQ. IN.
RESPONSE: MILLISECONDS

BUSHIPS DWG. NO. 023420

DATE: 8 FEB. 1946
CODE 332
DRAWN BY: C.M.FLYNN

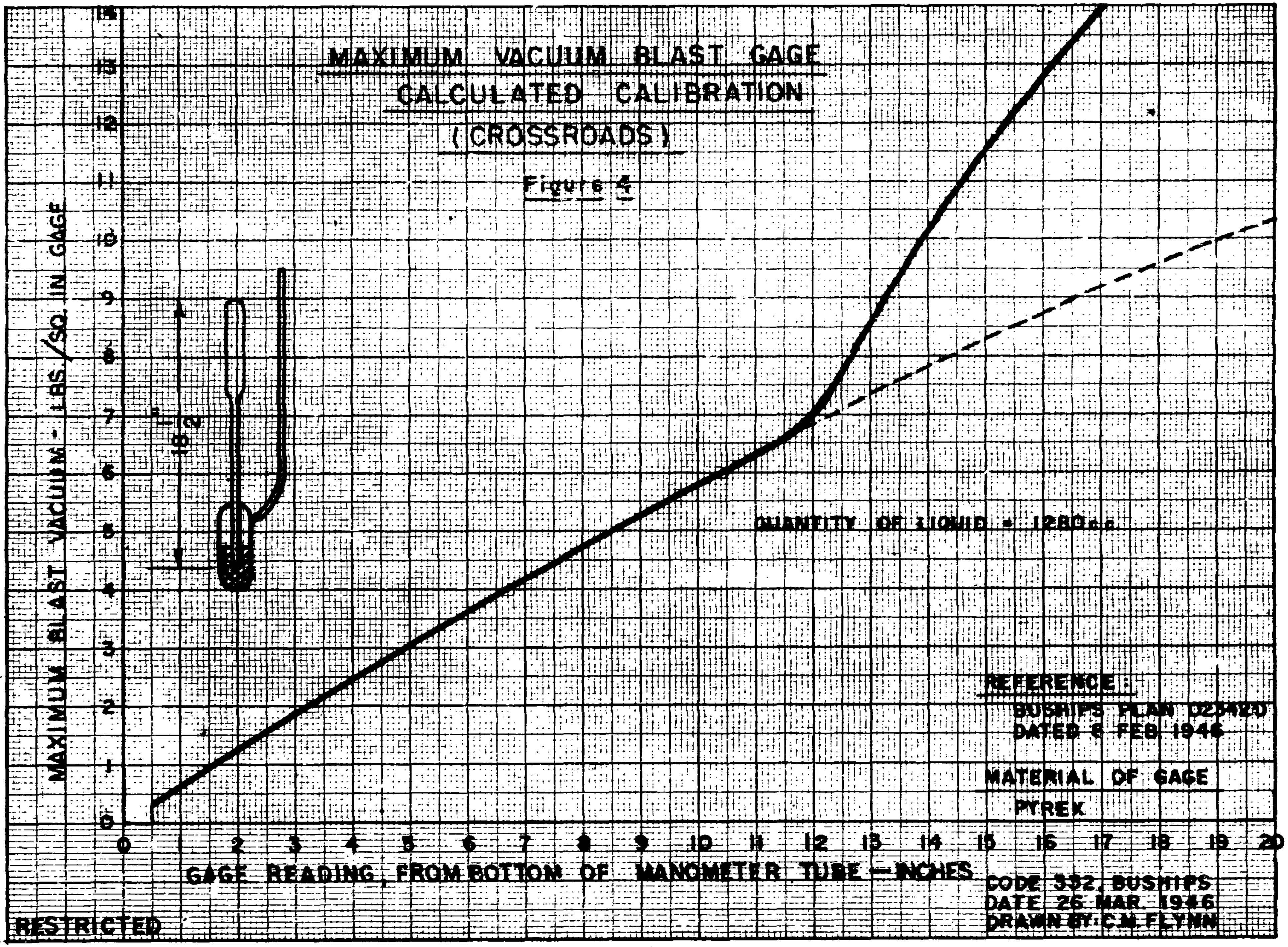
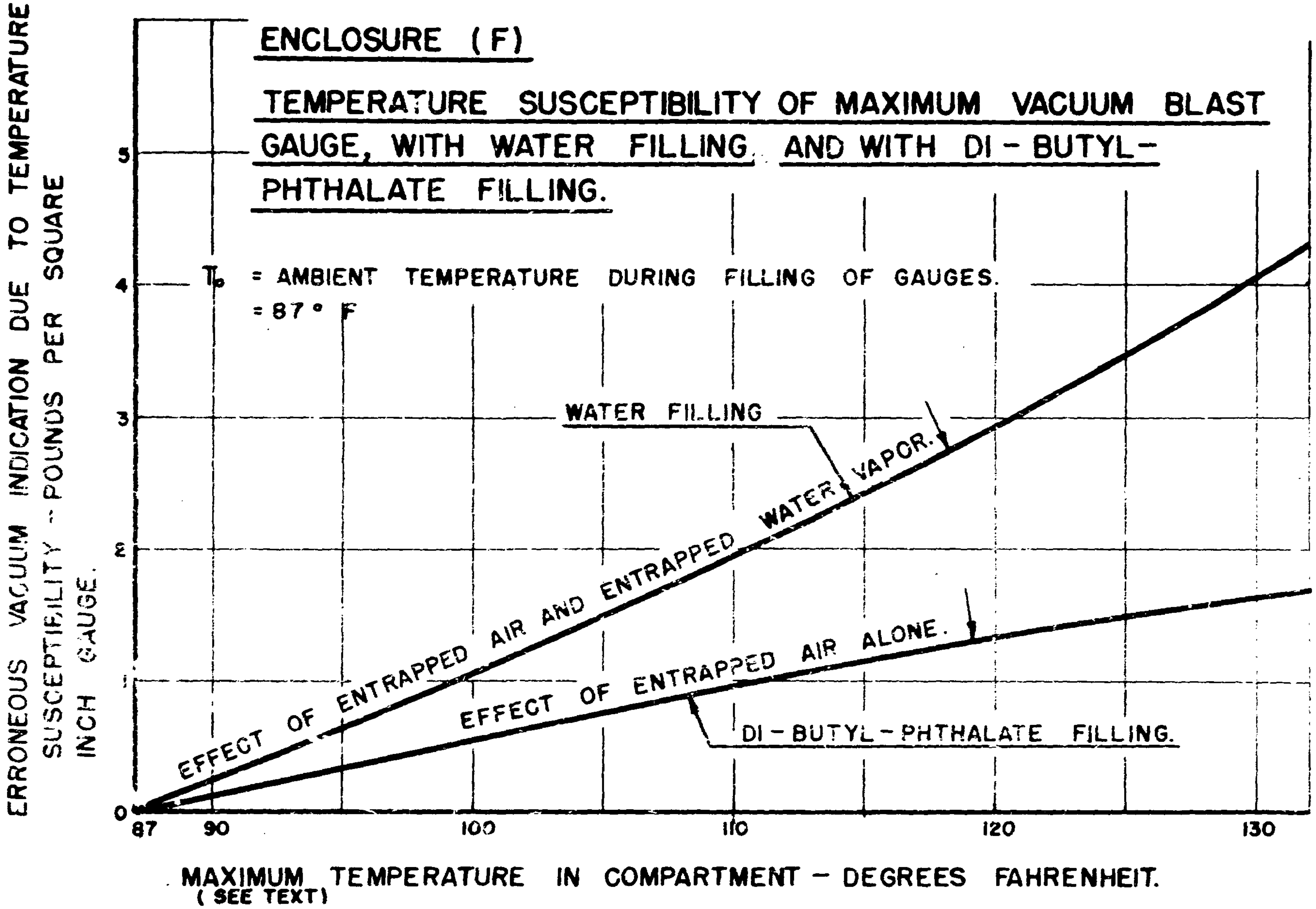


Figure 4

RESTRICTED

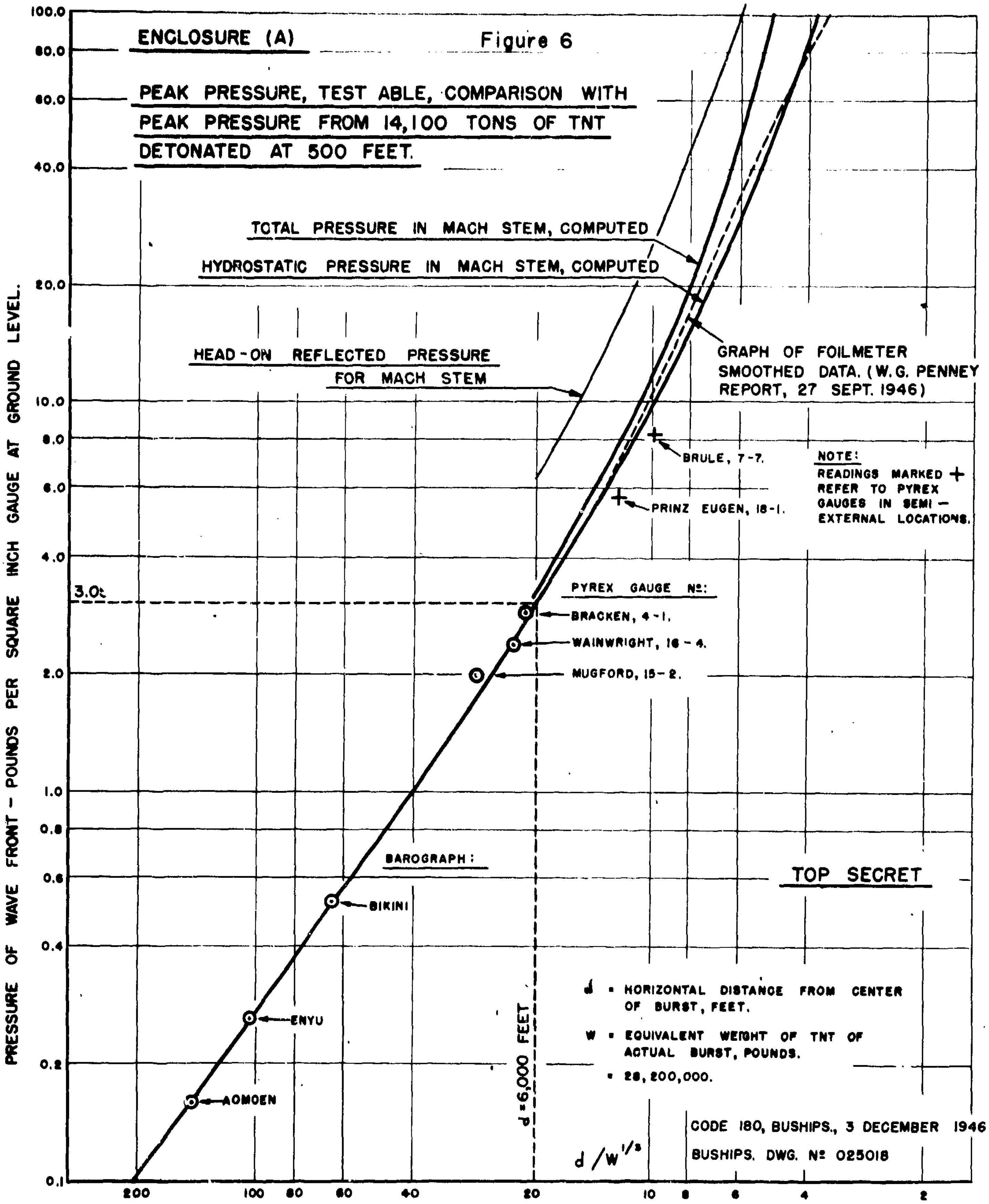
ENCLOSURE (F)

TEMPERATURE SUSCEPTIBILITY OF MAXIMUM VACUUM BLAST GAUGE, WITH WATER FILLING, AND WITH DI-BUTYL-PHTHALATE FILLING.



CODE 332, BUSHIPS. **RESTRICTED** 20 SEPT. 1946.

Figure 5 BUSHIPS. DWG. № 025009



ENCLOSURE (A)
Figure 6
PEAK PRESSURE, TEST ABLE, COMPARISON WITH PEAK PRESSURE FROM 14,100 TONS OF TNT DETONATED AT 500 FEET.
TOTAL PRESSURE IN MACH STEM, COMPUTED
HYDROSTATIC PRESSURE IN MACH STEM, COMPUTED
HEAD-ON REFLECTED PRESSURE FOR MACH STEM
GRAPH OF FOILMETER SMOOTHED DATA. (W. G. PENNEY REPORT, 27 SEPT. 1946)
BRULE, 7-7.
PRINZ EUGEN, 18-1.
NOTE: READINGS MARKED + REFER TO PYREX GAUGES IN SEMI-EXTERNAL LOCATIONS.
PYREX GAUGE No:
BRACKEN, 4-1.
WAINWRIGHT, 16-4.
MUGFORD, 15-2.
BAROGRAPH:
BIKINI
ENYU
AOMOEN
TOP SECRET
d = HORIZONTAL DISTANCE FROM CENTER OF BURST, FEET.
W = EQUIVALENT WEIGHT OF TNT OF ACTUAL BURST, POUNDS.
= 28,200,000.
d = 6,000 FEET
3.0±
CODE 180, BUSHIPS., 3 DECEMBER 1946
BUSHIPS. DWG. No 025018
$d/W^{1/3}$
PRESSURE OF WAVE FRONT - POUNDS PER SQUARE INCH GAUGE AT GROUND LEVEL.
100.0
80.0
60.0
40.0
20.0
10.0
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
200
100
80
60
40
20
10
8
6
4
2

ENCLOSURE B

PEAK PRESSURE, TEST ABLE, WEATHER STATIONS

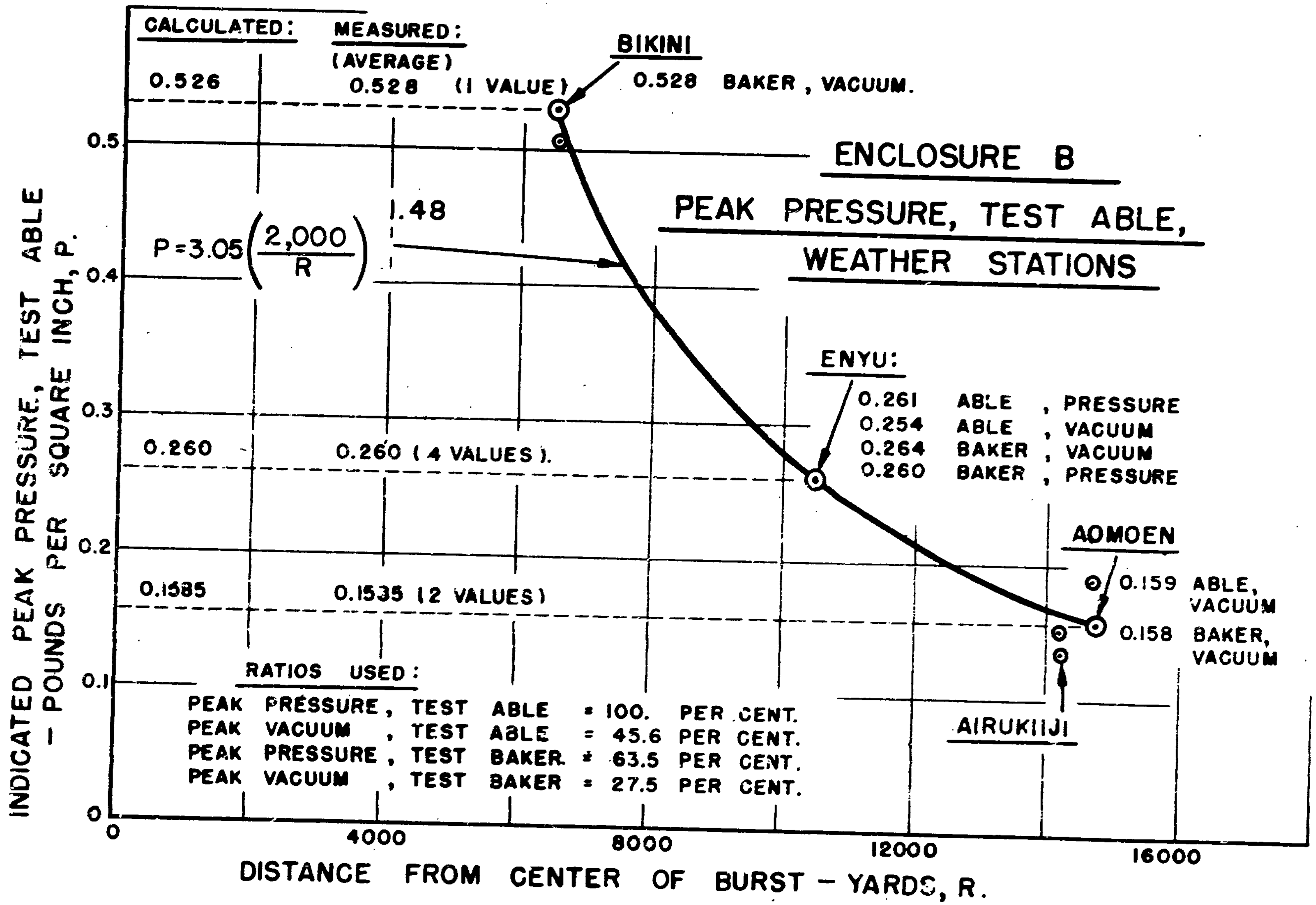


Figure 7

CODE 180, BUSHIPS., 24 OCT. 1946

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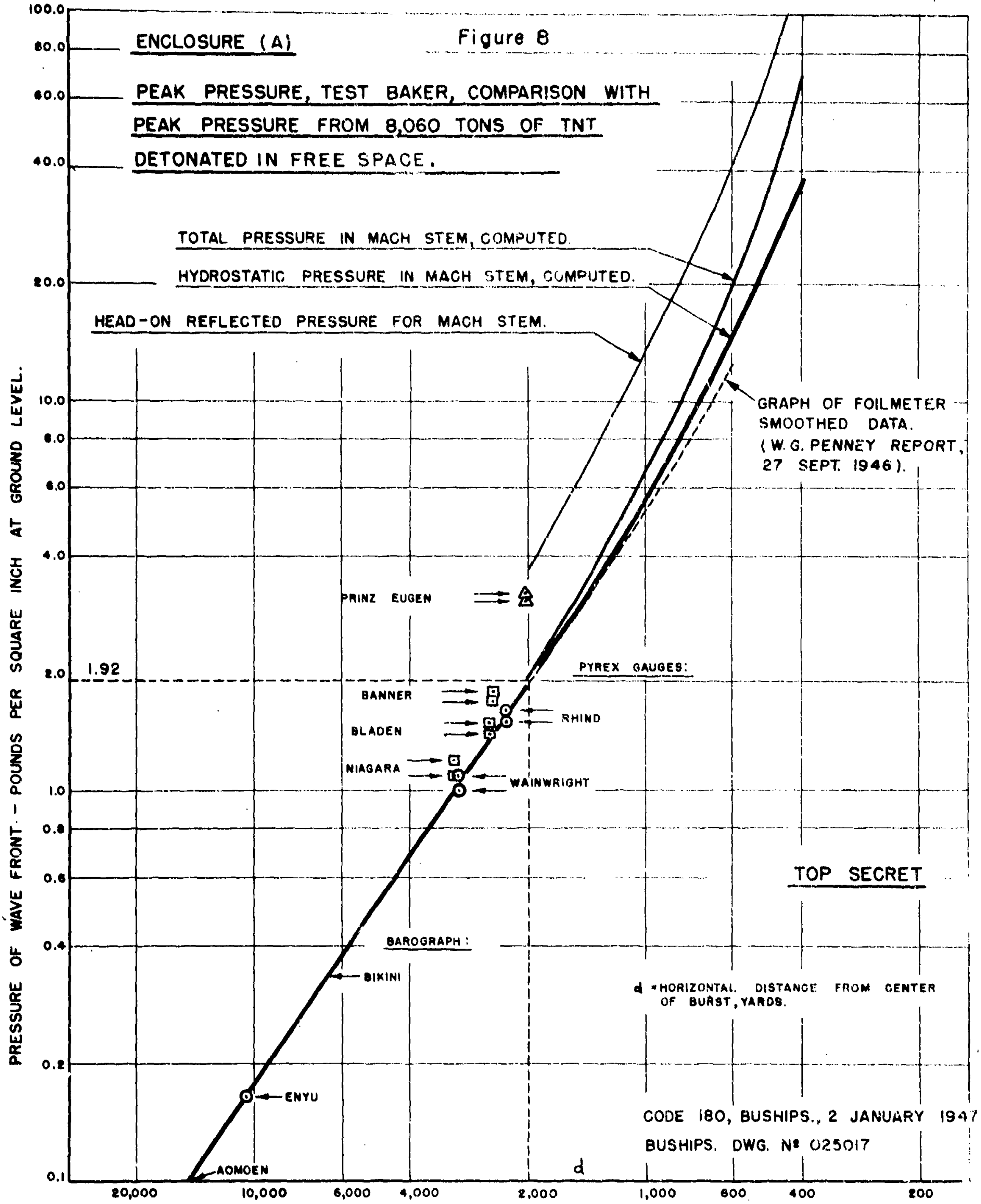
BUSHIPS. DWG. № 025010


ENCLOSURE (A)
Figure 8
PEAK PRESSURE, TEST BAKER, COMPARISON WITH PEAK PRESSURE FROM 8,060 TONS OF TNT DETONATED IN FREE SPACE.
TOTAL PRESSURE IN MACH STEM, COMPUTED.
HYDROSTATIC PRESSURE IN MACH STEM, COMPUTED.
HEAD-ON REFLECTED PRESSURE FOR MACH STEM.
GRAPH OF FOILMETER SMOOTHED DATA. (W. G. PENNEY REPORT, 27 SEPT. 1946).
PRESSURE OF WAVE FRONT - POUNDS PER SQUARE INCH AT GROUND LEVEL.
100.0
80.0
60.0
40.0
20.0
10.0
8.0
6.0
4.0
2.0
1.92
1.0
0.8
0.6
0.4
0.2
0.1
PRINZ EUGEN
PYREX GAUGES:
BANNER
BLADEN
NIAGARA
RHIND
WAINWRIGHT
TOP SECRET
BAROGRAPH:
BIKINI
d = HORIZONTAL DISTANCE FROM CENTER OF BURST, YARDS.
ENYU
AOMOEN
d
20,000
10,000
6,000
4,000
2,000
1,000
600
400
200
CODE 180, BUSHIPS., 2 JANUARY 1947
BUSHIPS. DWG. Nº 025017

ENCLOSURE (B)

PEAK PRESSURE, TEST BAKER

$$\frac{P\ \text{PRESSURE, BAKER}}{P\ \text{PRESSURE, ABLE}} = 0.63$$

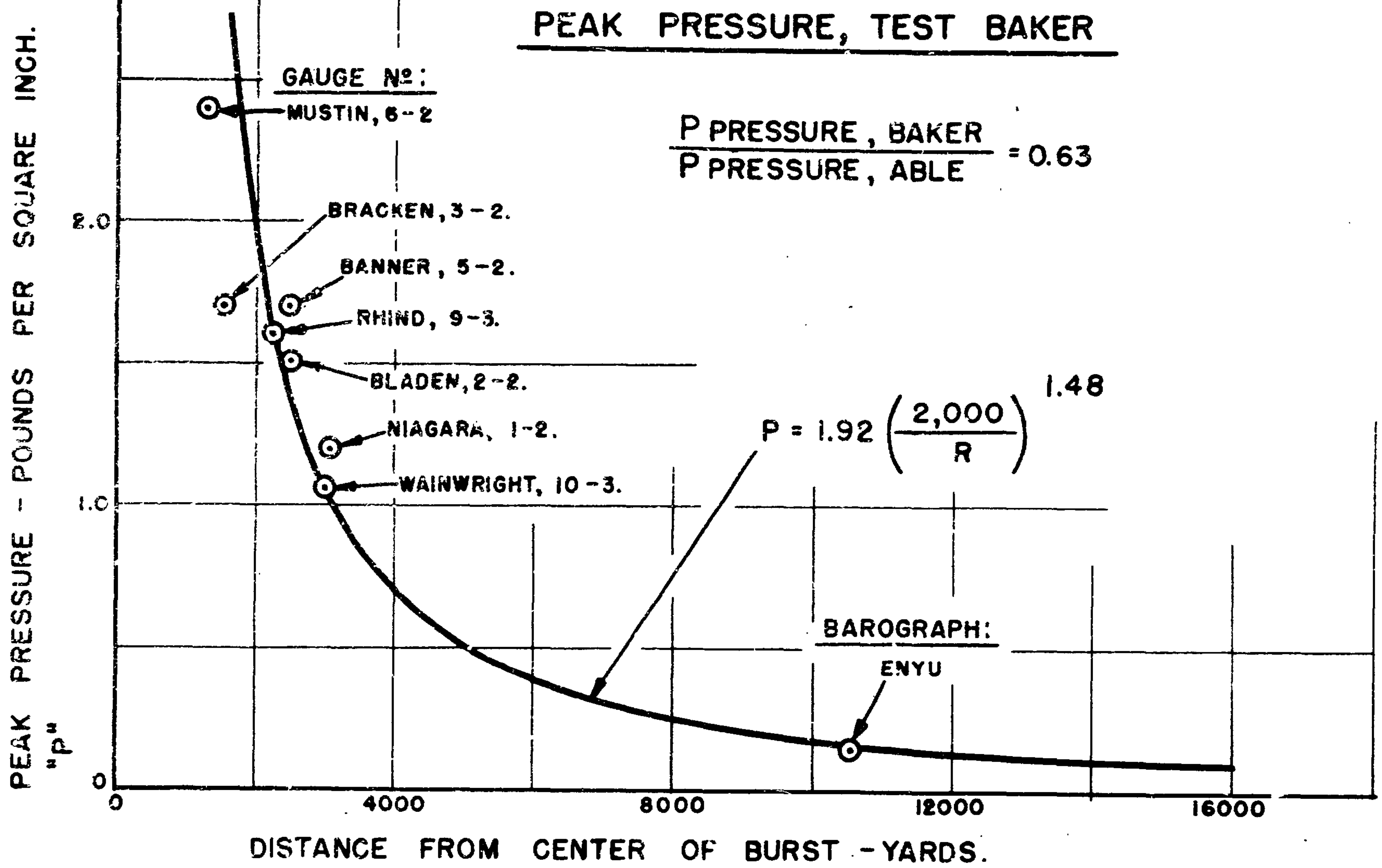


Figure 9

TOP SECRET

CODE 18C, BUSHIPS., 24 OCT. 1946

BUSHIPS. DWG. Nº 025014

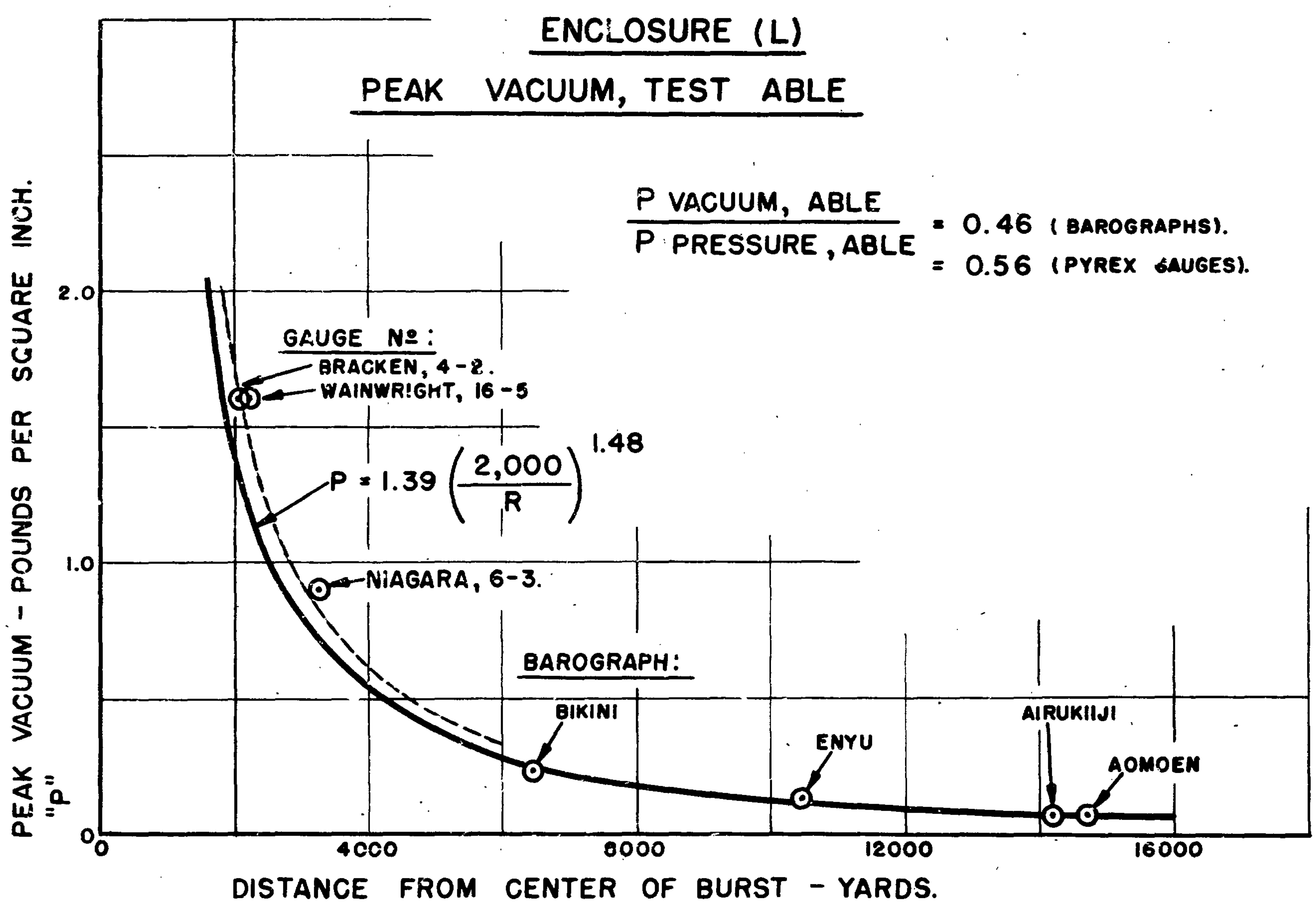


Figure 10

CODE 180, BUSHIPS., 24 OCT. 1946

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BUSHIPS. DWG. No 025013

ENCLOSURE (A)

PEAK VACUUM, TEST BAKER

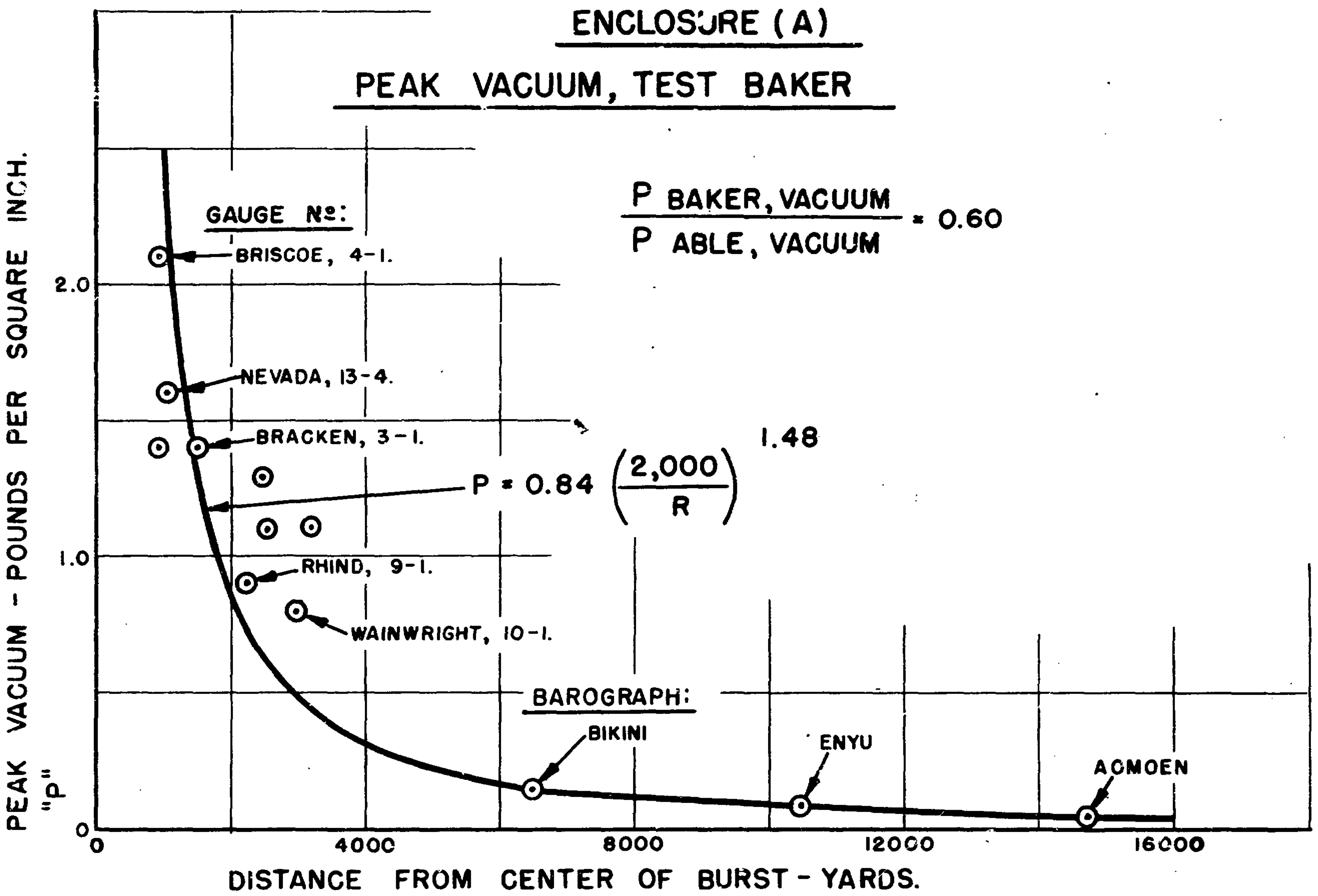


Figure II

CODE 180, BUSHIPS.. 24 OCT. 1946

TOP SECRET

BUSHIPS. DWG. № 025016

ENCLOSURE (A)

FIRE ROOM PRESSURES, TEST ABLE

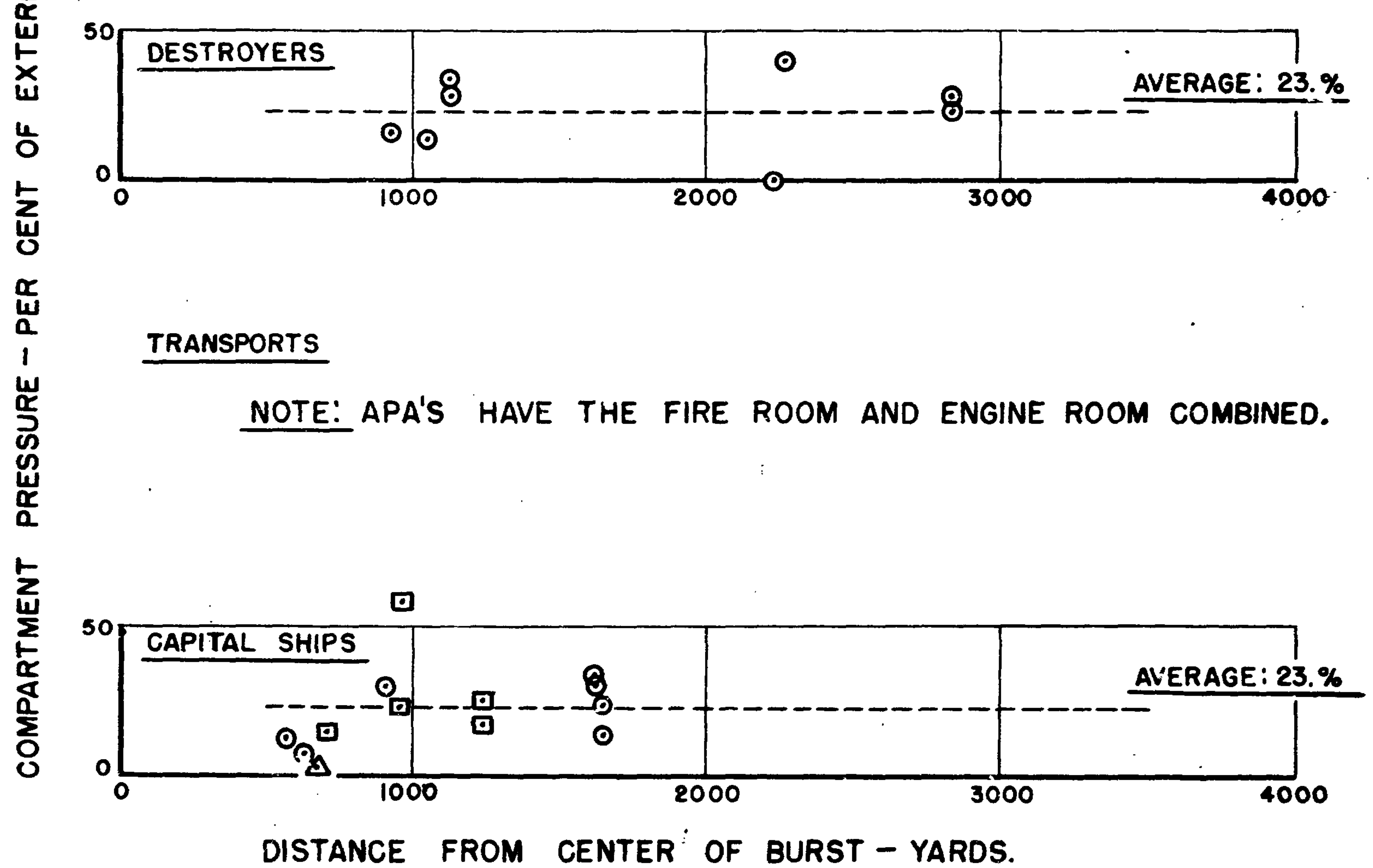


Figure 12

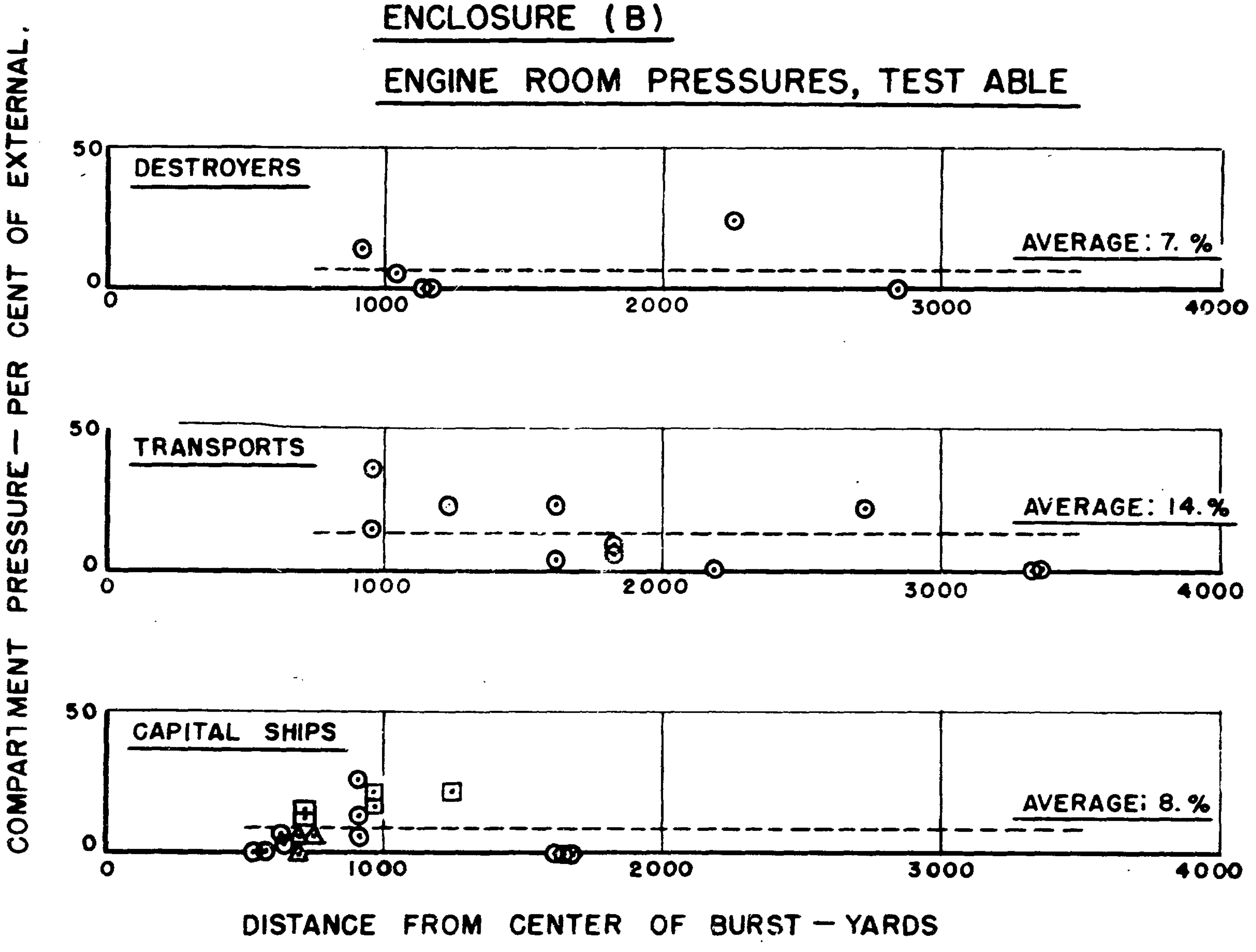
TOP SECRET

CODE 332, BUSHIPS., 20 JAN. 1947

BUSHIPS. DWG. № 025002.

ENCLOSURE (B)

ENGINE ROOM PRESSURES, TEST ABLE



TOP SECRET

Figure 13

CODE 332, BUSHIPS., 20 JAN. 1947

BUSHIPS. DWG. Nº 025003

ENCLOSURE (C)

BERTHING SPACE PRESSURES[1], TEST ABLE

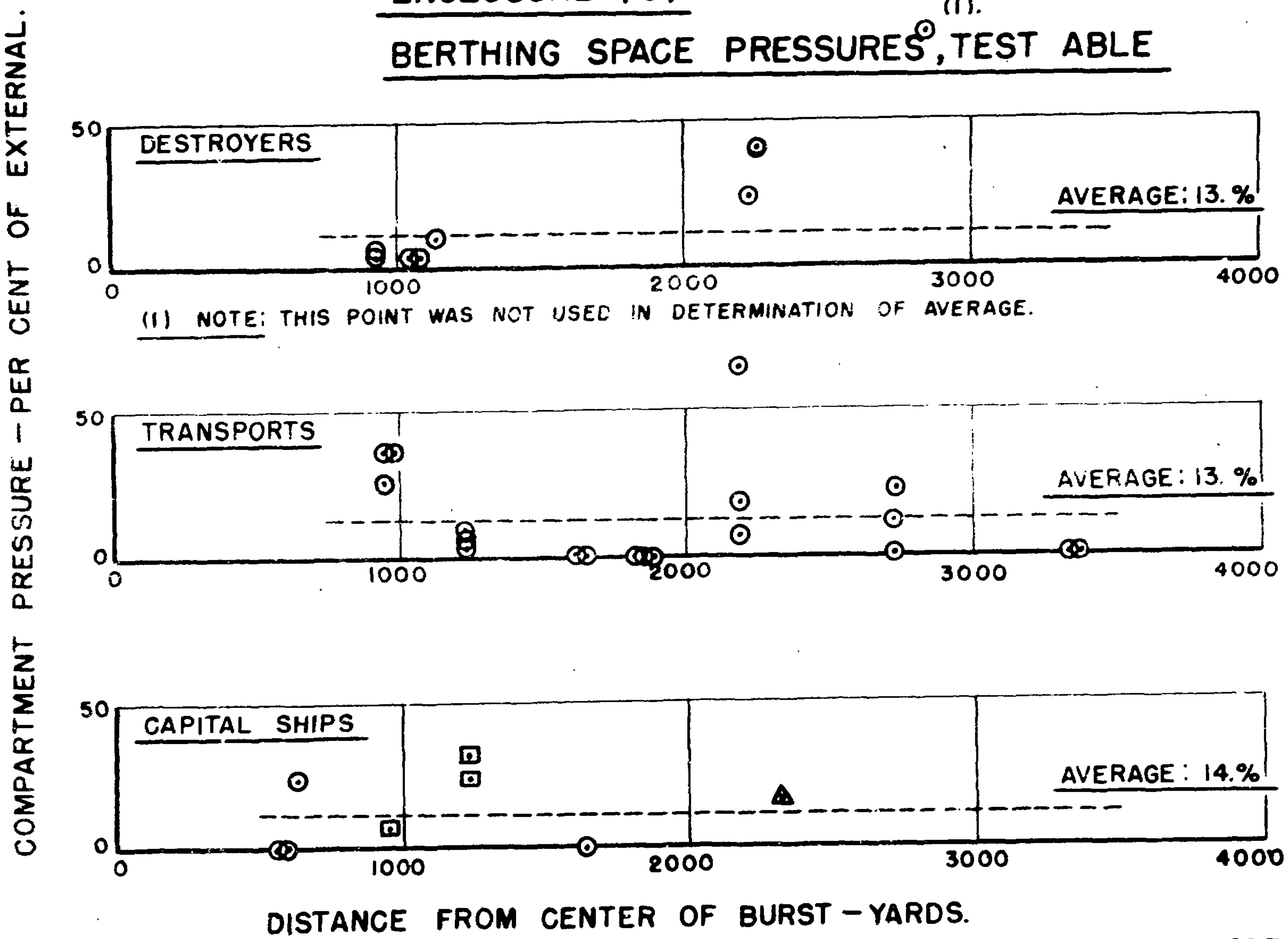


Figure 14

TOP SECRET

CODE 332, BUSHIPS., 20 JAN. 1947

BUSHIPS. DWG. Nº 025004

ENCLOSURE (D)

WARDROOM AND CABIN PRESSURES, TEST ABLE

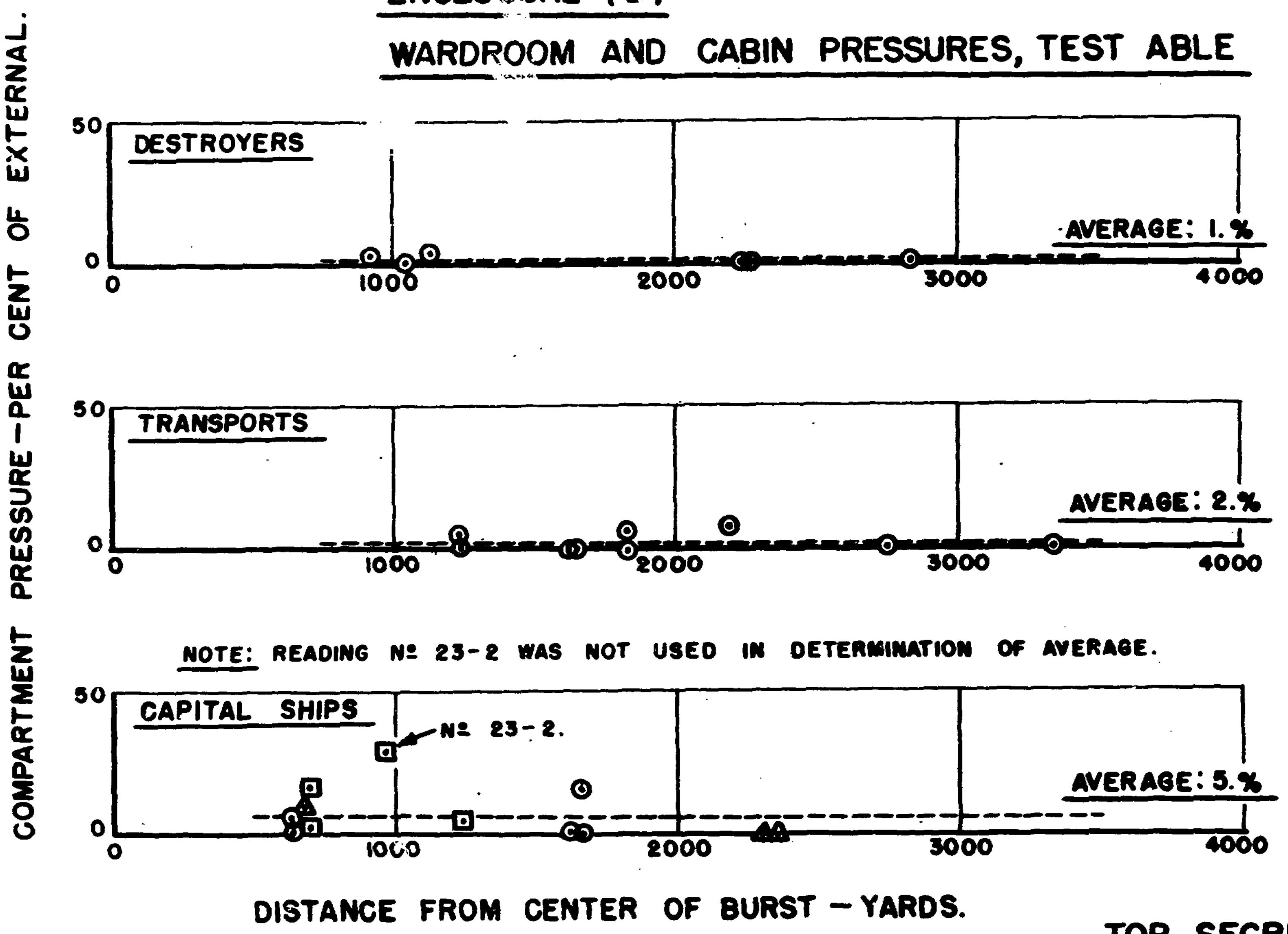


Figure 15

TOP SECRET

CODE 332, BUSHIPS., 20 JAN. 1947

BUSHIPS. DWG. № 025005

ENCLOSURE (G)

EXTERNAL PEAK PRESSURE, TEST ABLE

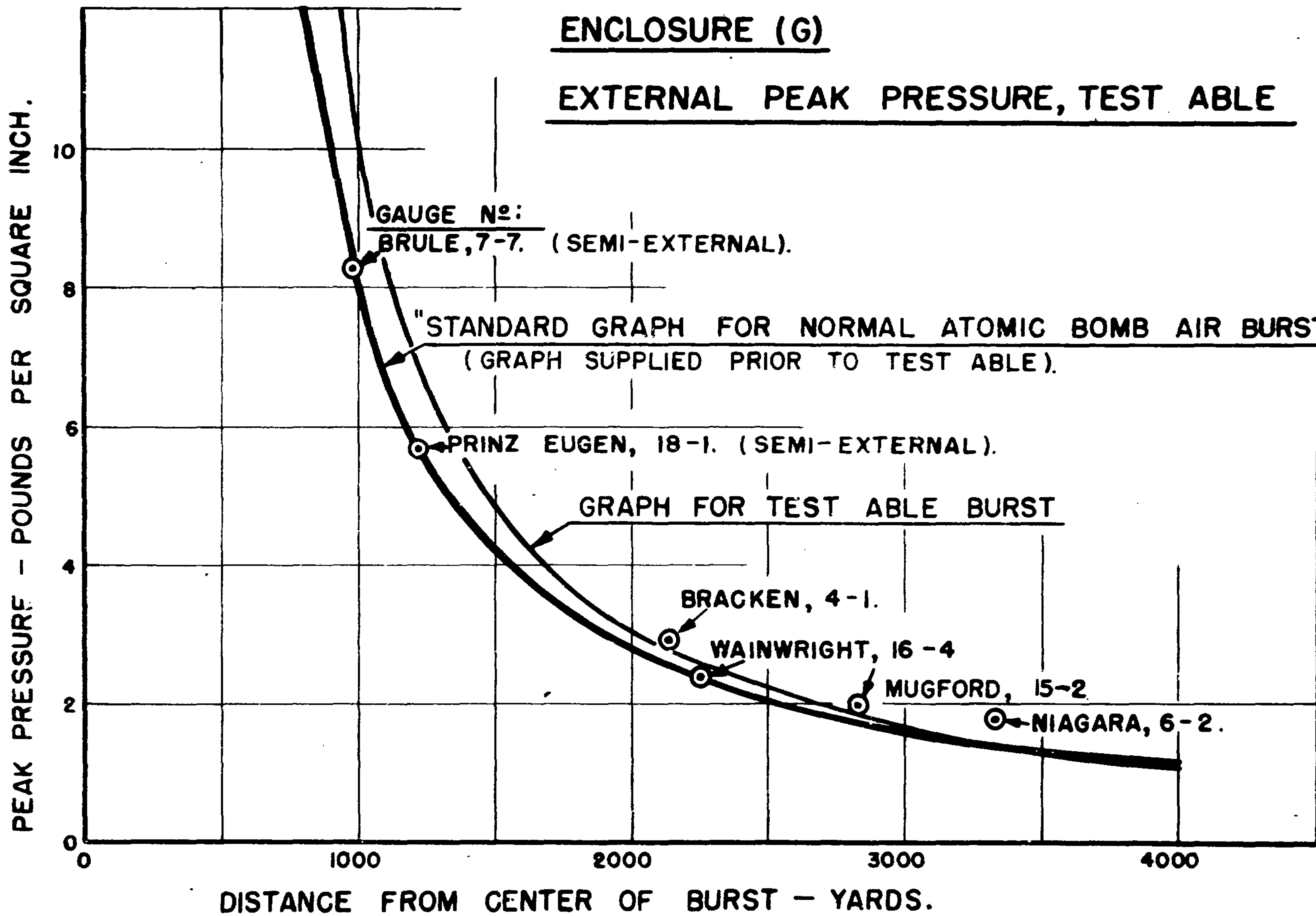


Figure 16

CODE 332, BUSHIPS, 23 DEC. 1946
REVISED: 13 JAN. 1947

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BUSHIPS. DWG. Nº 025000

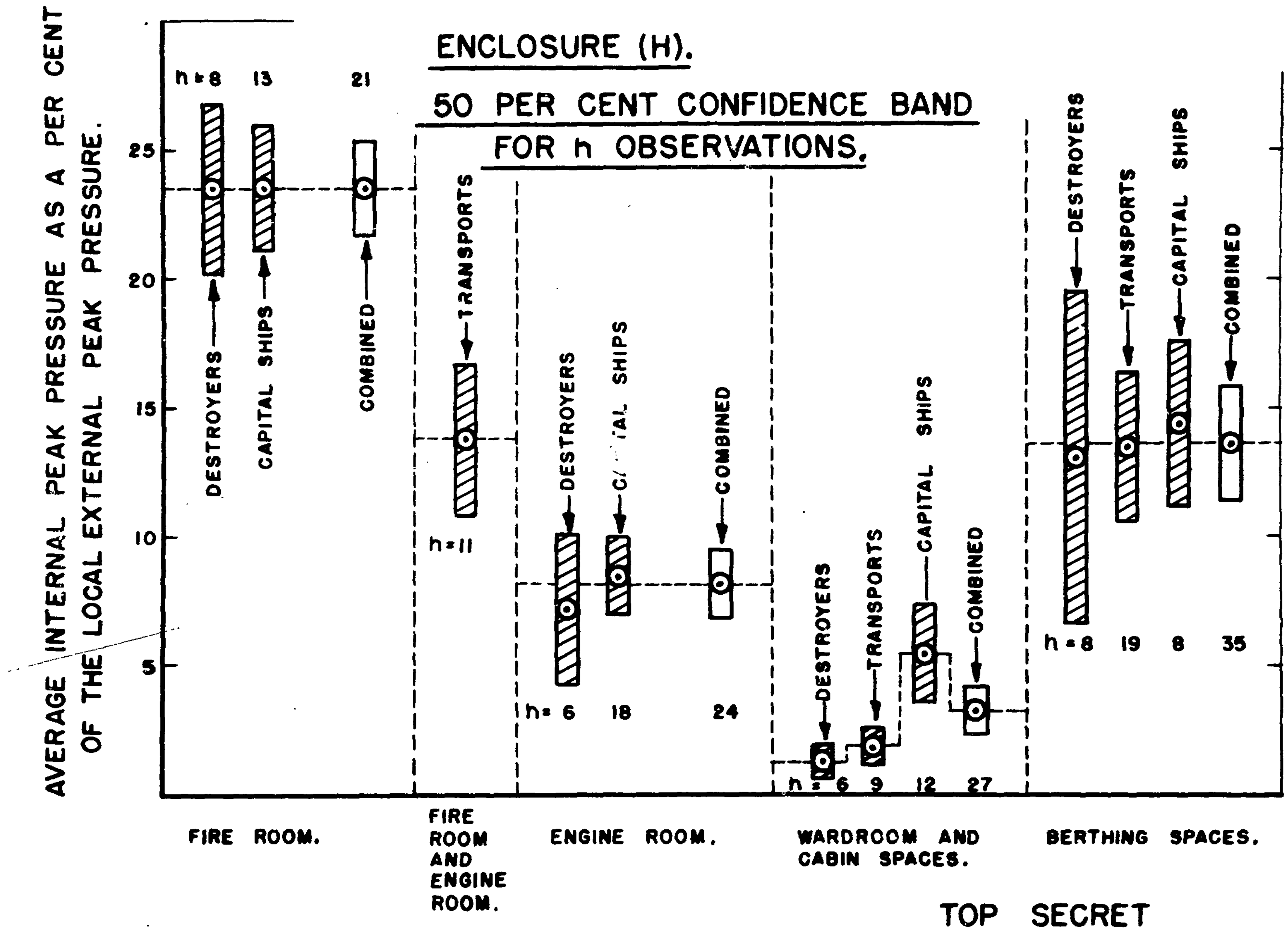

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Figure 17

CODE 332, BUSHIPS., 7 MARCH 1947

BUSHIPS. DWG. Nº 025022

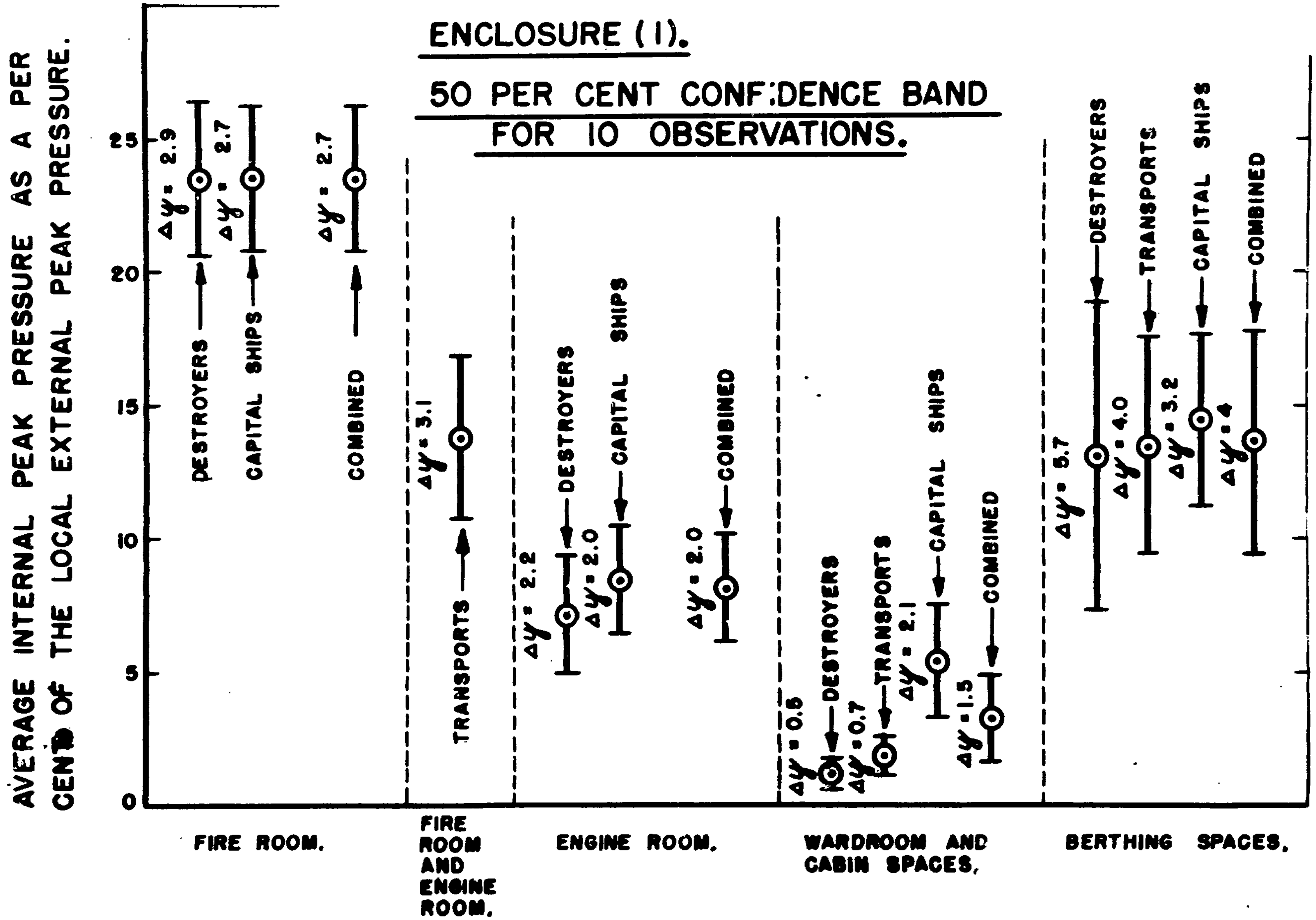

Figure 18

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CODE 332, BUSHIPS., 7 MARCH 1947

BUSHIPS. DWG. Nº 025023

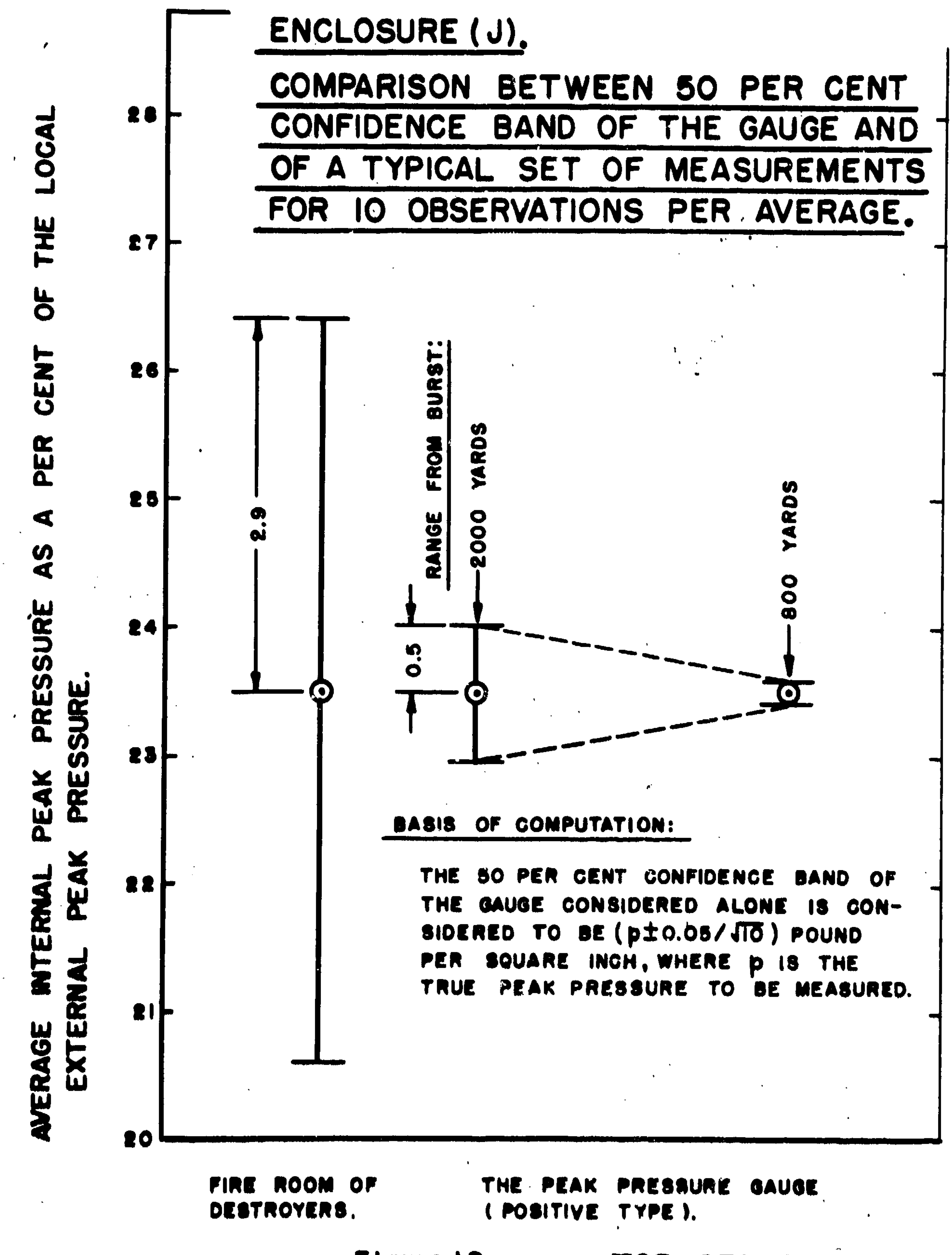

Figure 19

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CODE 332, BUSHIPS. 7 MARCH 1947 BUSHIPS. DWG. № 025024

CONFIDENTIAL

ENCLOSURE (K).

EFFECT OF TYPE OF BOILER CASING (50 PER CENT CONFIDENCE BAND FOR h OBSERVATIONS).

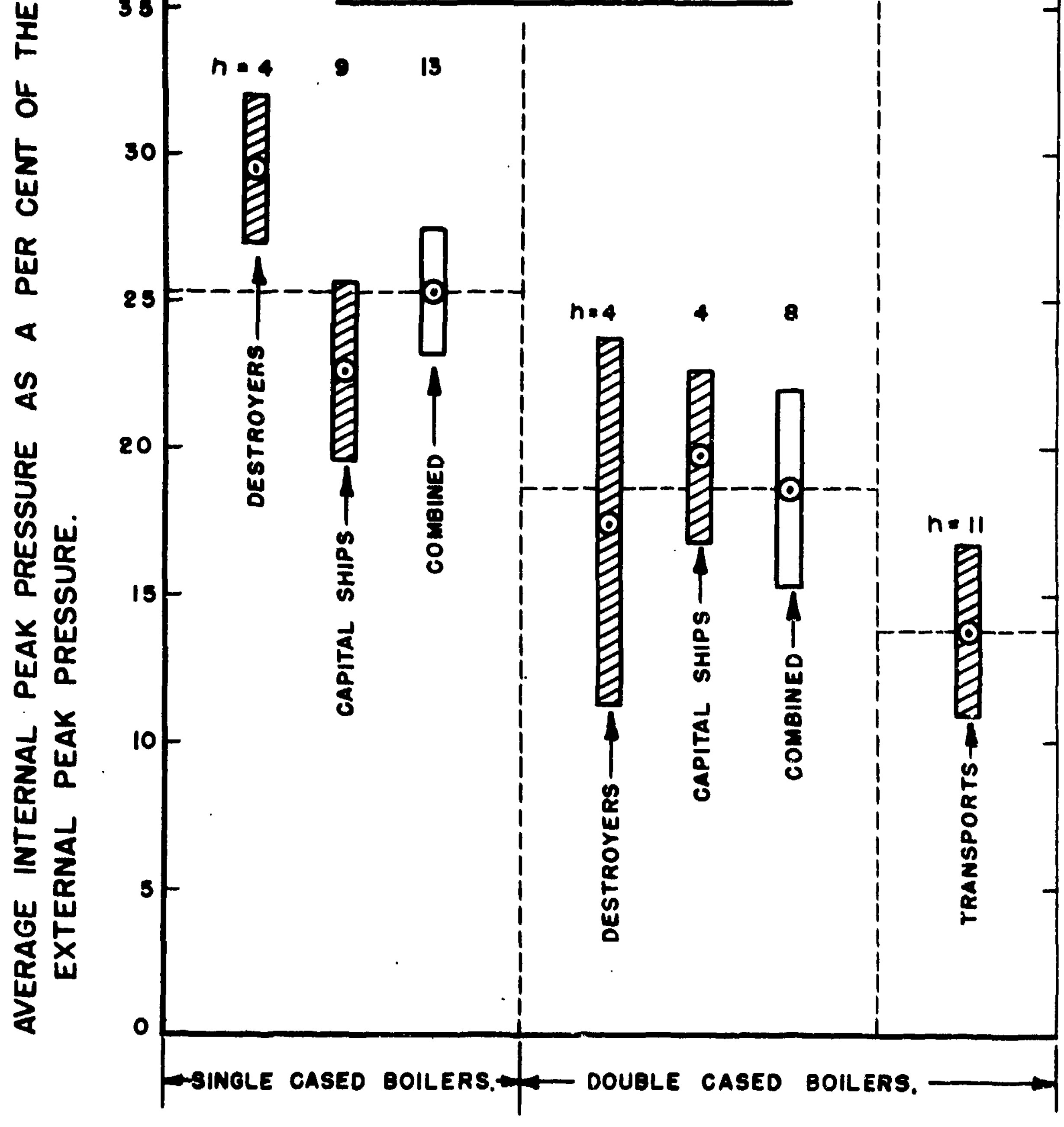

Figure 20 [redacted]

CODE 332, BUSHIPS., 7 MARCH 1947 — BUSHIPS. DWG. № 025025

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ATOMIC ENERGY ACT 1946

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ATOMIC ENERGY ACT 1946

Defense Special Weapons Agency
6801 Telegraph Road
Alexandria, Virginia 22310-3398

TRC

18 April 1997

MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER
ATTENTION: OMI/Mr. William Bush (Security)

SUBJECT: Declassification of Reports

The Defense Special Weapons Agency has declassified the following reports:

AD-366588	XRD-203-Section 12
AD-366589	XRD-200-Section 9
AD-366590	XRD-204-Section 13
AD-366591	XRD-183
AD-366586	XRD-201-Section 10
AD-367487	XRD-131-Volume 2
AD-367516	XRD-143
AD-367493	XRD-142
AD-801410L	XRD-138
AD-376831L	XRD-83
AD-366759	XRD-80
AD-376830L	XRD-79
AD-376828L	XRD-76
AD-367464	XRD-106
AD-801404L	XRD-105-Volume 1
AD-367459	XRD-100

TRC

18 April 1997

Subject: Declassification of Reports

AD-801406L XRD-114

In addition, all of the cited reports are now **approved for public release; distribution statement "A" now applies.**

Ardith Jarrett

ARDITH JARRETT

Chief, Technical Resource Center